Front. Optoelectron. 2014, 7(1): 91–101
DOI 10.1007/s12200-014-0392-8

RESEARCH ARTICLE

Climate effects on performance of free space optical communication systems in Yemen

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Abstract Free space optical (FSO) communication has been considered as an alternative to radio relay link line-of-sight (LOS) communication systems. The total attenuation is a combination of atmospheric attenuation in the atmosphere and geometric losses. The purpose of this paper is to study the geometric loss versus link range (in km), divergence angle, transmitter aperture diameter, and receiver aperture diameter. Total attenuation versus low visibility, average visibility, beam divergence, link range and rainfall rate were presented in this paper. Atmospheric attenuation (in dB) and scattering coefficient (in km^{-1}) for several Yemeni main cities were explored. The study was concentrated on received power versus low and average visibilities and link range. Series of related simulation results were illustrated and discussed in this paper about the climate effects on performance of FSO communication systems in Yemen.

Keywords free space optics (FSO), total attenuation, geometric losses, haze, fog, rain, receive power

1 Introduction

Free space optics (FSO) communication uses light propagating in free space to wirelessly transmit data for telecommunications or computer networking. Free space means air, outer space, vacuum, or something similar. Operating wavelengths in this paper are at 780, 850 and 1550 nm. FSO is useful tool in situations, where the physical connections are impracticable due to high cost or other considerations. This technology uses invisible beams of light to provide optical bandwidth connections and form broadband access networks. It has the ability of sending up to 1.25 Gbps of data, voice, and video communications simultaneously. The most advantages of FSO are easy-to-install, lower cost, no interference, and license-free. In this paper, we introduced climate effects on FSO communication in Yemen and illustrated several related simulation results.

In the frame of the present work, our objective is to develop our earlier studies as presented in Refs. [1,2]. In Ref. [1], the effect of atmospheric turbulence on FSO systems in Yemen was analyzed by using an appropriate model and we found the effect of atmospheric turbulence on FSO communication in Yemen at three different intensities, namely strong, medium, and weak turbulence, for three different wavelengths, namely 780, 850, and 1550 nm. We also presented simulation results to validate our approach in Ref. [1]. Two criteria had been used to evaluate our method, namely bit error rate (BER) and signal to noise ratio (SNR). Those results indicated that the performance of the FSO system is good despite the worst conditions in Yemen. To improve the transmission efficiency of FSO systems, the wavelength of 1550 nm must be used and the distance between transmitter and receiver must be reduced. To achieve a BER of 10^{-9} during air turbulence, the distance between transmitter and receiver should be 2600 m. Thus, the FSO system may be applied in Yemen efficiently even in the case of the presence of air turbulence. While in Ref. [2], we took Yemen as a case study. In some mountainous areas in Yemen, it is difficult to install the technique of fiber optics. FSO technique can solve this problem with same proficiency and quality provided by fiber optics. However, FSO systems are sensitive to bad weather conditions, such as fog, haze, dust, rain and turbulence. All of these conditions can attenuate light and block the light path into the atmosphere. As a result of these challenges, we have to study weather conditions in detail before installing FSO systems. This is to reduce effects of the atmosphere and ensure that the transmitted power is sufficient and loss is minimal during bad weather. Generally, the study was concentrated on the effects of haze, rain and turbulence on the FSO systems. Although much work has been done toward developing FSO and most techniques have been

Received December 2, 2013; accepted December 27, 2013

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reported [3–8], it is better to indicate more recent development in the field of FSO communication to the reader.

2 Formulation

Atmospheric attenuation is defined as the process whereby some or all of the electromagnetic wave energy is lost when traversing the atmosphere[1]. Thus, atmosphere causes signal degradation and attenuation in a FSO system link in several ways, including absorption, scattering, and scintillation. All these effects are varying with time and depend on the current local conditions and weather. In general, the atmospheric attenuation is given by the following Beer's law equation [9]:

$$\tau = \exp(-\beta L), \tag{1}$$

where,

τ is the atmospheric attenuation,

β is the total attenuation coefficient and given as

$$\beta = \beta_{\text{abs}} + \beta_{\text{scat}}, \tag{2}$$

L is the distance between transmitter and receiver (unit: km),

β_{abs} is the molecular and aerosol absorption, this parameter value is considered as too small, so we can neglected,

β_{scat} is the molecular and aerosol scattering.

The geometric path loss for a FSO link depends on the beam-width of the optical transmitter θ, its path length L and the area of the receiver aperture A_{r}. The transmitter power, P_{t} is spread over an area of $\pi(L\theta)^2/4$. Geometric loss is the ratio of the surface area of the receiver aperture to the surface area of the transmitter beam at the receiver. Since the transmit beams spread constantly with increasing range at a rate determined by the divergence, geometric loss depends primarily on the divergence as well as the range and can be determined by the formula stated as [10]

$$\text{geometric loss} = \frac{d_2^2}{[d_1 + (L\theta)]^2}, \tag{3}$$

where,

d_2 is the diameter receiver aperture (unit: m),

d_1 is the diameter transmitter aperture (unit: m),

θ is the beam divergence (unit: mrad),

L is the link range (unit: m).

Geometric path loss is presented for all FSO links and must always be taken into consideration in the planning of any link. This loss is a fixed value for a specific FSO deployment scenario; it does not vary with time, unlike the loss induced by rain attenuation, fog, haze or scintillation. Atmospheric attenuation of FSO system is typically dominated by haze, fog and is also dependent on rain. The total attenuation is a combination of atmospheric attenuation in the atmosphere and geometric loss. Total attenuation for FSO system is actually very simple at a high level (leaving out optical efficiencies, detector noises, etc.). The total attenuation is given by the following [11]:

$$\frac{P_{\text{r}}}{P_{\text{t}}} = \frac{d_2^2}{[d_1 + (L\theta)]^2} \times \exp(-\beta L), \tag{4}$$

where,

P_{t} is the transmitted power (unit: mW),

P_{r} is the received power (unit: μW),

θ is the beam divergence (unit: mrad),

β is the total scattering coefficient (unit: km^{-1}).

According to Eq. (4), the variables which can be controlled are the aperture size, the beam divergence and the link range. The scattering coefficient is uncontrollable in an outdoor environment. In real atmospheric situations, for availabilities at 99.9% or better, the system designer can choose to use huge transmitter laser powers, design large receiver apertures, design small transmitter apertures and employ small beam divergence. Another variable that can be controlled is link range, which must be of a short distance to ensure that the atmospheric attenuation is not dominant in the total attenuation [12]. The strength of scintillation can be measured in terms of the variance of the beam amplitude or irradiance σ_{i} given by the following:

$$\sigma_{\text{i}}^2 = 1.23 C_n^2 k^{7/6} L^{11/6}. \tag{5}$$

Here, $k = 2\pi/\lambda$ is the wave number and this expression suggests that longer wavelengths experience a smaller variance, and C_n^2 is a refractive index structure parameter. Equation (5) is valid for the condition of weak turbulence mathematically corresponding to $\sigma_{\text{i}}^2 < 1$. Expressions of lognormal field amplitude variance depend on the nature of the electromagnetic wave traveling in the turbulence and on the link geometry [13].

In this paper, we did not take into account the atmospheric turbulence, because its influence on Yemeni climate could be negligible. That means the effect of the turbulence is too small, which is opposite to visibility and geometric loss. Therefore, we had taken into account only the total attenuation depending on visibility, and geometric loss.

A FSO communication system is influenced by atmospheric attenuation, which limits its performance and reliability. The atmospheric attenuated by fog, haze, rainfall, and scintillation has a adverse effect on FSO system. The majority of the scattering occurred on the laser beam is Mie scattering. This scattering is due to the fog and haze aerosols at the atmosphere and can be calculated through visibility. FSO attenuation at thick fog can reach values of hundreds dB. Thick fog reduces the visibility

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1) http://en.wikipedia.org/wiki/Optics (25 October, 2013)

range to less than 50 m, and it can affect on the performance of FSO link for distances. The rain scattering (non-selective scattering) is independent on wavelength, and it does not introduce significant attenuation in wireless infrared links, but it affects mainly on microwave and radio systems that transmit energy at longer wavelengths. There are three effects on turbulence: scintillation, laser beam spreading and laser beam wander. Scintillation is due to variation in the refractive index of air. If the light is traveled by scintillation, it will experience intensity fluctuations. The geometric loss depends on FSO components design such as beam divergence, aperture diameters of both transmitter and receiver. The total attenuation depends on atmospheric attenuation and geometric loss. To reduce total attenuation, the effect of geometric loss and atmospheric attenuation should be small in a designed FSO system. The following section presents the simulation results of geometric loss and total attenuations for Yemeni climate.

3 Simulation results and discussion of geometric loss and total attenuation

3.1 Geometric loss

This part illustrates the effects of geometric loss on the performance of FSO system. We calculated the value of geometric loss using Eq. (3) assuming that the link range is 1 km and beam divergence is 1 mrad at two different designs. The particular design specifications are shown in Table 1, and particular implementation especially is based on the existing product available in the industry [14].

Table 1 Diameters of transmitter and receiver aperture of FSO system

design	diameter of transmitter aperture/cm	diameter of receiver aperture/cm
design 1	8	10
design 2	3.5	7

There are a number of parameters that control geometric loss: transmission range, diameters of transmitter and receiver apertures and laser beam divergence. These parameters also contribute to the design of FSO system, so that it can be suitable during bad weather conditions.

Figure 1 shows the geometric loss versus link range using the values presented in Table 1 and the divergence angle is about 0.025 mrad. The link range is from 0.5 to 5.0 km. Geometric loss is proportional to link range, which increases with the enhancement of link range. As demonstrated in Fig. 1, the geometric loss is 1.3 dB at 0.5 km for design 1 and −3.4 dB for design 2. While at the distance of 5 km, the geometric loss for design 1 reaches 8.2 dB and 7.2 dB for design 2. Figure 2 illustrates the geometric loss versus the divergence angle. The divergence angle ranges from 0.025 to 0.070 mrad. As the divergence angle increases, geometric loss enhances. For a 0.025 mrad divergence angle, the geometric loss is about 1.93 dB for design 1 and −10.5 dB for design 2. For a 0.070 mrad divergence angle, the geometric loss is about 4.6 dB for design 1 and −5.6 dB for design 2. That means by using a small divergence angle of laser beam in FSO systems, geometric loss effect can be minimized.

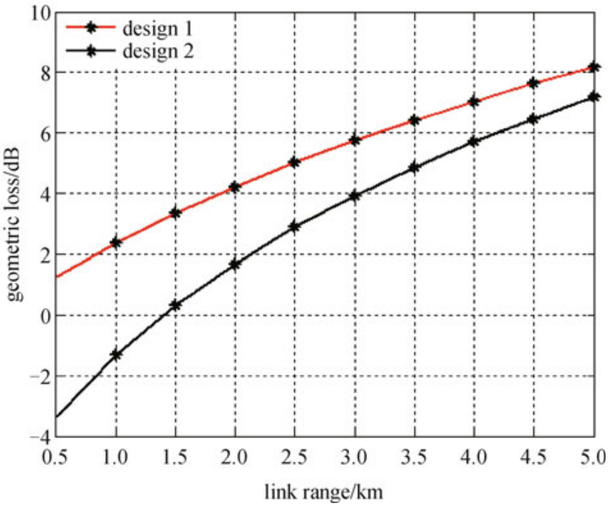

Fig. 1 Geometric loss (dB) versus link range (km)

Figure 3 demonstrates the geometric loss versus the transmitter aperture diameter using the values presented in Table 1, the divergence angle is about 0.025 mrad and the link range is 1 km. The transmitter aperture diameter is in the range of 2 to 22 cm. This figure shows that the transmitter aperture diameter rises with increases of the geometric loss. For transmitter aperture diameter of 2 cm, the geometric loss is about −7 dB for design 1 and −3.87 dB for design 2. For the transmitter aperture diameter of 20

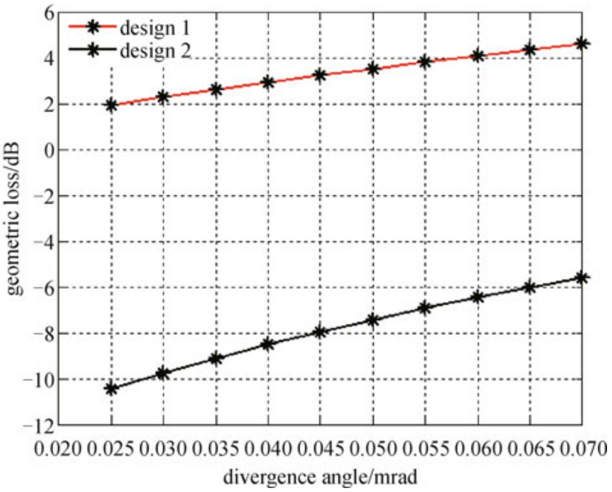

Fig. 2 Geometric loss (dB) versus divergence angle (mrad)

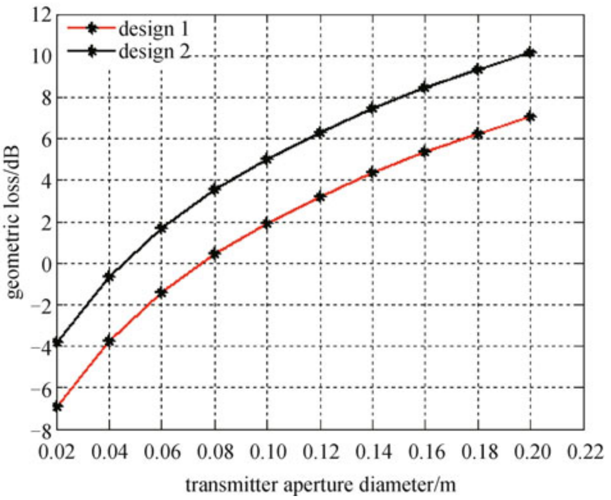

Fig. 3 Geometric loss (dB) versus transmitter aperture diameter (m)

cm, the geometric loss is about 7.7 dB for design 1 and 10.2 dB for design 2. That means the small transmitter aperture diameter is suggested to minimize in the geometric loss effect on FSO systems.

Figure 4 indicates the geometric loss versus the receiver aperture diameter using the values presented in Table 1, divergence angle is about 0.025 mrad and the link range is 1 km. When the receiver aperture diameter increases, the geometric loss decreases. For receiver aperture diameter of 2 cm, the geometric loss is about 14.4 dB for design 1 and 9.5 dB for design 2. For the receiver aperture diameter of 20 cm, the geometric loss is about −5.6 dB for design 1 and −10.5 dB for design 2. Obtained data shows that the large receiver aperture diameter can be used to reduce the geometric loss effect on the FSO systems. The results of geometric losses with design parameters are presented in Table 2. We note that the geometric loss at low values for receiver aperture diameter is high compared to the upper values. The aperture diameter of receiver is smaller than that of transmitter.

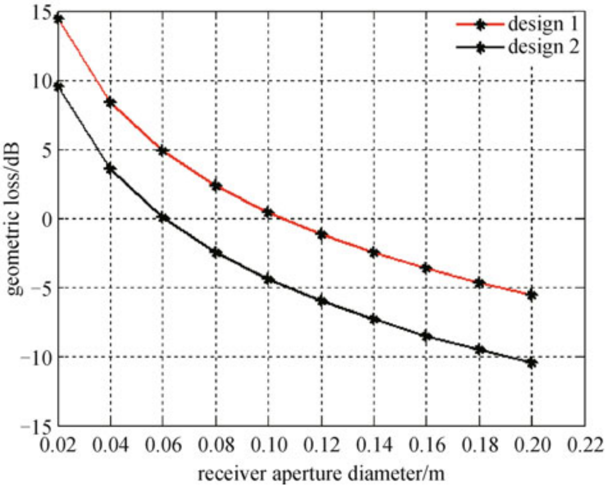

Fig. 4 Geometric loss (dB) versus receiver aperture diameter (m)

3.2 Total attenuation

Total attenuation depends on attenuation resulted from hazy and rainy days and geometric loss. The attenuation in hazy days depends on visibility, while during rainy days it would be determined by rainfall rate. Visibility changes with the quantity and density of particles, such as fog, haze and dust attached to air. When the density of the particles increases, consequently the visibility range will be lower. As a result, the total attenuation increases. The density of these particles keeps varying with time and place as well as rainfall. The quantity and density of these particles are unpredictable, and visibility and rainfall rate are also uncontrollable. Thus, they are all not part of FSO design.

We can only control the value of geometric loss, because it depends on fixed parameters such as transmitter diameter, receiver apertures, transmission range, and beam divergence. During the design of FSO system, geometric loss must be at minimum to reduce the effect of total attenuation on FSO system. In this part, we used the parameters of design 2 as demonstrated in Table 1 to calculate total attenuation because in this design geometric loss is less as described above in Section 3.1.

3.2.1 Total attenuation during hazy days

Figure 5 shows total attenuation at low visibility. We used Eq. (2) to plot Fig. 5. Here, we assume that link range is 1 km. When visibility is 0.8 km, total attenuations are 31.8, 31 and 26.4 dB at wavelengths of 780, 850 and 1550 nm, respectively. And when visibility is 5 km, total attenuation are 16.8, 16.4, and 15.4 dB for wavelengths of 780, 850 and 1550 nm, respectively. From the previous results, we note that at high visibility, the effect of total attenuation on the FSO system will be less.

Figure 6 indicates the total attenuation versus average visibility. When visibility is 6.4 km, total attenuation is 15.96, 15.8 and 14.9 dB at wavelengths of 780, 850 and 1550 nm, respectively. Note that when visibility is 9.7 km, total attenuation are of 15.39, 15.28 and 14.7 dB at wavelengths of 780, 850 and 1550 nm, respectively. Based on the previously mentioned, we conclude that total attenuation at wavelength 1550 nm is less than that at wavelengths of 780 and 850 nm. Therefore, to reduce the effect of total attenuation during hazy days, we use the wavelength of 1550 nm.

Figure 7 represents total attenuation versus link range. From this figure, we find that total attenuation is directly proportional to link range. When link range is 0.5 km, total attenuation is 17.3, 16.9 and 14.6 dB at wavelengths of 780, 850 and 1550 nm, respectively. In addition, when link

Table 2 Results of geometric loss with design parameters

design parameters	geometric loss/dB			
	design 1		design 2	
	from	to	from	to
link range	1.3	8.2	–3.4	7.2
divergence angle	1.93	4.6	–10.5	–5.6
receiver aperture diameter	14.8	–5.2	10.4	–9.8
transmitter aperture diameter	–6	7.2	–2.9	10.3

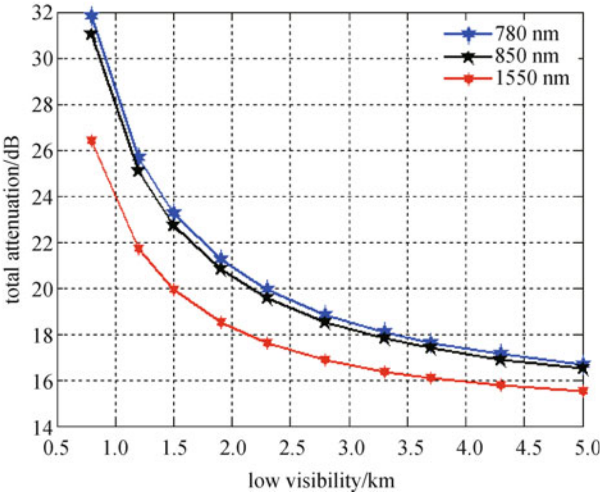

Fig. 5 Total attenuation (dB) versus low visibility (km)

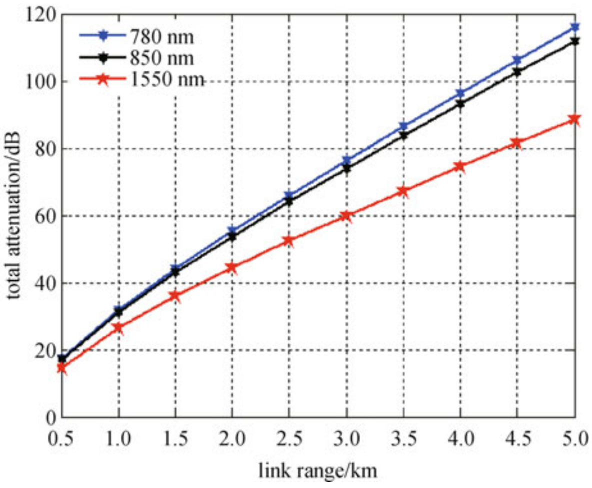

Fig. 7 Total attenuation (dB) versus link range (km)

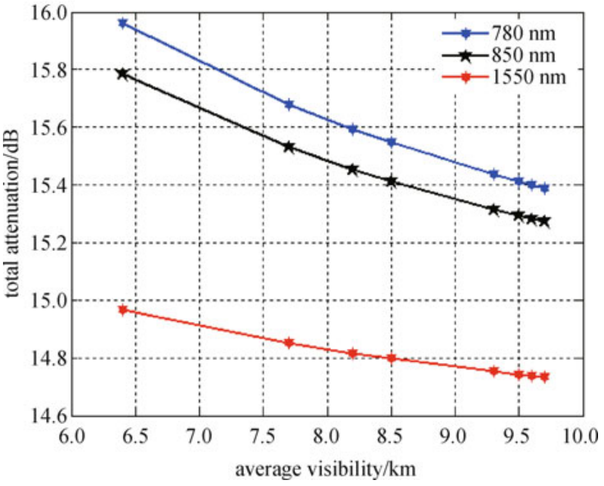

Fig. 6 Total attenuation (dB) versus average visibility (km)

range is 5 km, total attenuation becomes 115.0, 111.8 and 88.4 dB at wavelengths of 780, 850 and 1550 nm, respectively. Therefore, to reduce the effect of total attenuation on FSO, the distance between the transmitter and receiver should be small. Figure 8 shows the relationship between total attenuation and laser beam divergence for three wavelengths. With increasing the beam divergence, the total attenuations are increased for three cases as demonstrated in Fig. 8. That means when the beam divergence at 1 mrad, the total attenuations are 32, 31, and 26 dB for wavelengths 780, 850, and 1550 nm, respectively. While at beam divergence of 10 mrad, we noticed that the total attenuation was increased 51.1, 50.8, and 46 dB for three previously indicated wavelengths. Therefore, to reduce atmospheric attenuation, the beam divergence should be small in accordance with the previous results. Table 3 shows the results of total attenuation for design parameters at hazy days.

3.2.2 Total attenuation in rainy days

Figure 9 shows the total attenuation versus rainfall rate. It can be seen obviously that the influence of attenuation on transmission of FSO systems is more prominent during heavy rainfall compared to moderate and light rainfalls. Figure 10 indicates the total attenuation versus link range. The atmospheric attenuation is proportional to link range, which shows that when the link range increases, the total attenuation increase as well. The results of total attenuation for design parameters at rainy days are presented in Table 4.

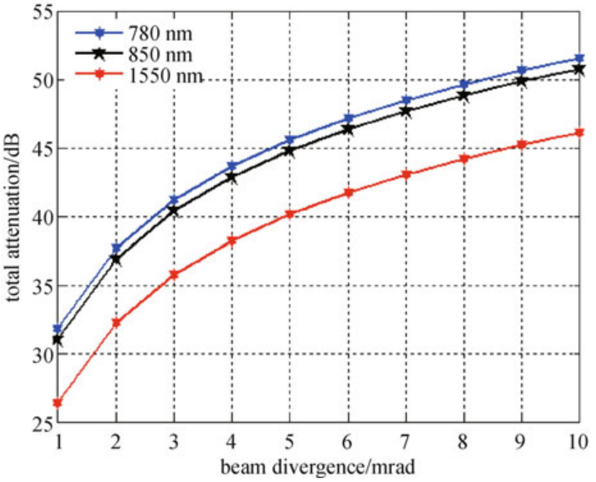

Fig. 8 Total attenuation (dB) versus laser beam divergence (mrad)

Table 3 Results of total attenuation for design parameters at hazy days

parameters	wavelength/nm	total attenuation/dB	
		from	to
low visibility	780	31.8	16.8
	850	31	16.4
	1550	26.4	15.4
average visibility	780	15.96	15.3
	850	15.8	15.3
	1550	14.9	14.7
link range	780	17.3	115
	850	16.9	111.8
	1550	14.6	88.4
beam divergence	780	32	51.6
	850	31	50.8
	1550	26	46

4 Simulation results and discussion of haze effects on FSO systems in Sana'a, Aden, and Taiz cities

In this section, we study the effect of atmospheric attenuation and scattering coefficient on the performance of FSO systems in Sana'a, Aden and Taiz cities.

4.1 Sana'a city

Low visibility range for Sana'a city in Fig. 11 extends from 0.3 to 6 km. Scattering coefficient at low visibility of 0.3 km is 11.37, 10.99 and 8.69 km^{-1} for wavelengths of 780, 850 and 1550 nm, respectively. The scattering coefficient of 6 km low visibility is 0.45, 0.41 and 0.21 km^{-1} for wavelengths of 780, 850, and 1550, respectively.

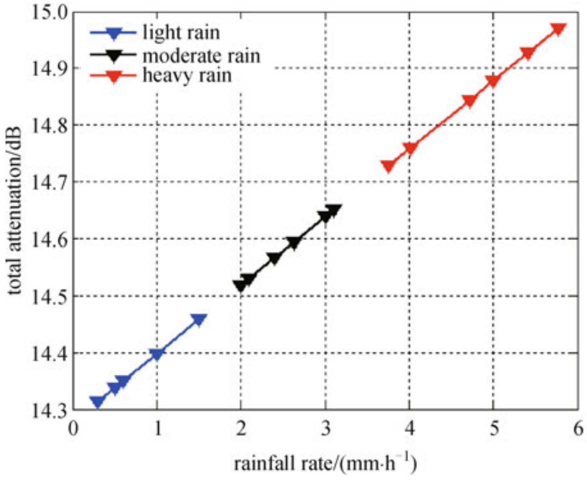

Fig. 9 Total attenuation (dB) versus rainfall rate (mm·h^{-1})

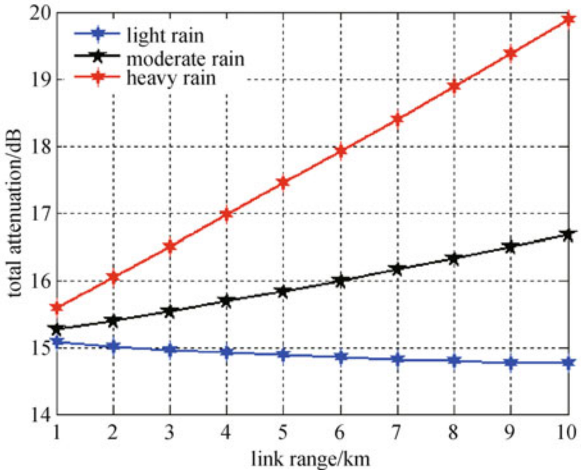

Fig. 10 Total attenuation (dB) versus link range (km)

Table 4 Results of total attenuation for design parameters at rainy days

parameters	rainfall	total attenuation/dB	
		from	to
rainfall rate	light	14.3	14.46
	moderate	14.5	14.67
	heavy	14.71	14.98
link range	light	15.1	15.5
	moderate	15.4	16.8
	heavy	15.6	20

Figure 12 shows that the atmospheric attenuation versus low visibility in Sana'a city. At low visibility of 0.3 km, atmospheric attenuation is 49.4, 47.7 and 37.7 dB for wavelengths of 780, 850 and 1550 nm, respectively. For 6 km low visibility, the atmospheric attenuation is about 2,

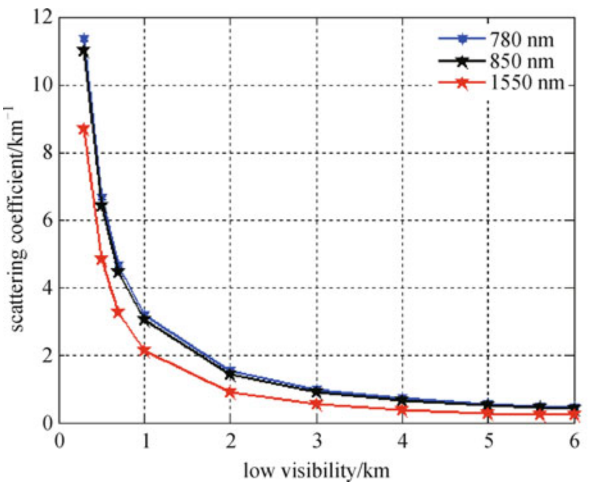

Fig. 11 Scattering coefficient (km^{-1}) versus low visibility for Sana'a city (km)

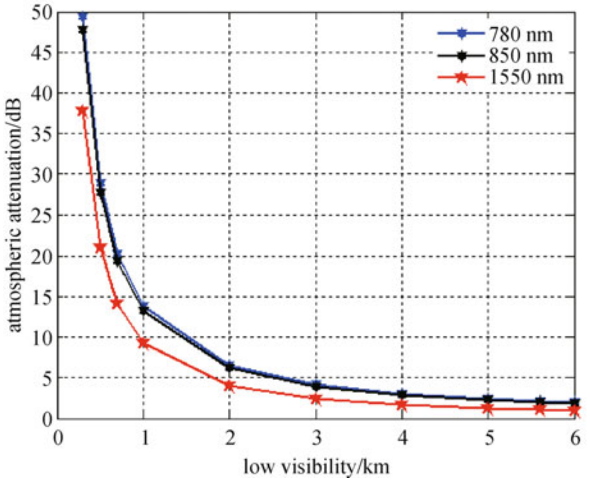

Fig. 12 Atmospheric attenuation (dB) versus low visibility (km) for Sana'a city

1.8 and 0.94 dB for wavelengths of 780, 850 and 1550 nm, respectively.

4.2 Aden city

Low visibility range in Fig. 13 extends from 0.05 to 6 km for Aden city. Scattering coefficient at low visibility 0.05 km is 44.8, 43.8 and 37.6 km^{-1} for wavelengths of 780, 850 and 1550 nm, respectively. The scattering coefficient of 6 km low visibility is 0.45, 0.41 and 0.22 km^{-1} for wavelengths 780, 850, and 1550 nm, respectively.

Figure 14 shows that the atmospheric attenuation versus low visibility for Aden city. At low visibility of 0.05 km, atmospheric attenuation is 194.4, 190.2 and 163.5 dB for wavelengths 780, 850 and 1550 nm, respectively. For 6 km low visibility, the atmospheric attenuation is about 1.95,

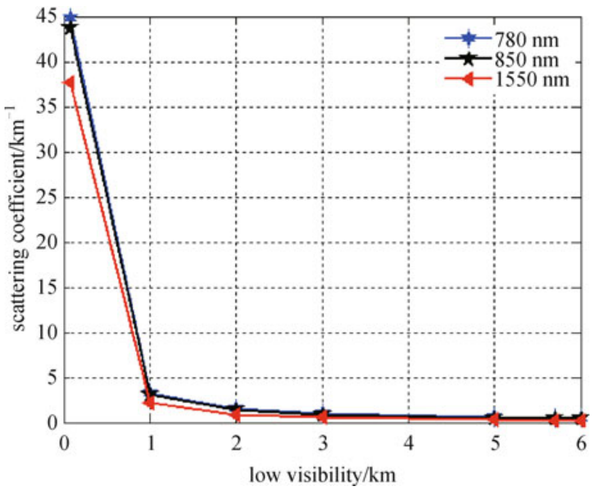

Fig. 13 Scattering coefficient (km^{-1}) versus low visibility (km) for Aden city

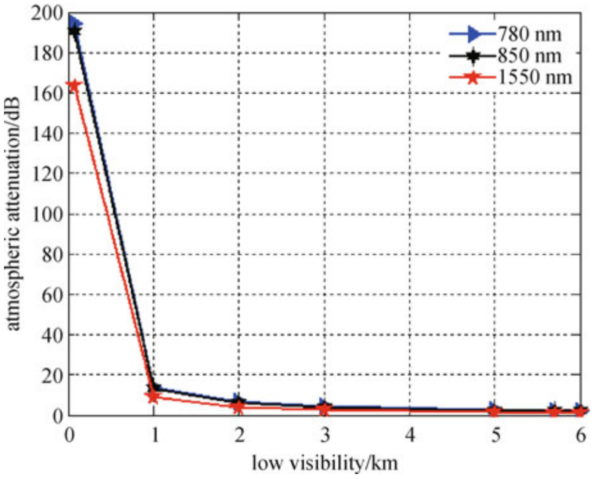

Fig. 14 Atmospheric attenuation (dB) versus low visibility (km) for Aden city

1.8 and 0.94 dB for wavelengths of 780, 850 and 1550 nm, respectively.

4.3 Taiz city

Low visibility range in Fig. 15 extends from 0.05 to 4 km for Taiz city. Scattering coefficient at low visibility 0.05 km is 44.8, 43.8 and 37.6 km^{-1} for wavelengths of 780, 850 and 1550 nm, respectively. The scattering coefficient of 4 km low visibility is 0.70, 0.65 and 0.37 km^{-1} for wavelengths of 780, 850, and 1550 nm, respectively. Figure 16 shows that the atmospheric attenuation versus low visibility for Taiz city. At low visibility of 0.05 km, atmospheric attenuation is 194.4, 190.2 and 163.5 dB for wavelengths of 780, 850 and 1550 nm, respectively. For 4 km low visibility, the atmospheric attenuation is about 3.1, 2.8 and 1.6 dB for wavelengths of 780, 850 and 1550 nm,

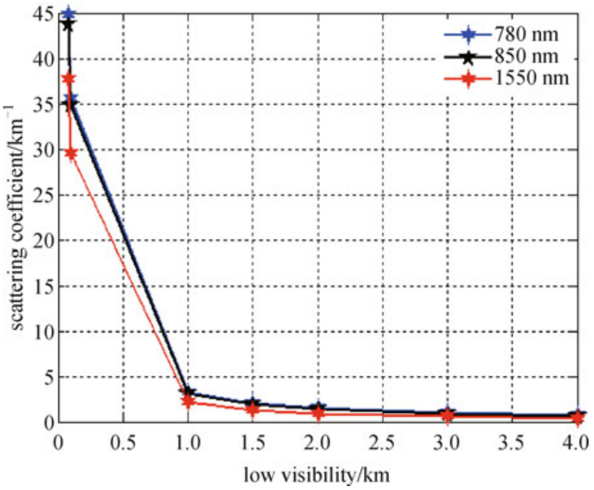

Fig. 15 Scattering coefficient (km^{-1}) versus low visibility (km) for Taiz city

respectively. Table 5 shows the results of scattering coefficient and atmospheric attenuation at low visibility for Sana'a, Aden and Taiz cities. The results show that with increasing the wavelength, the scattering coefficient and atmospheric attenuation decrease for the three cases in this paper.

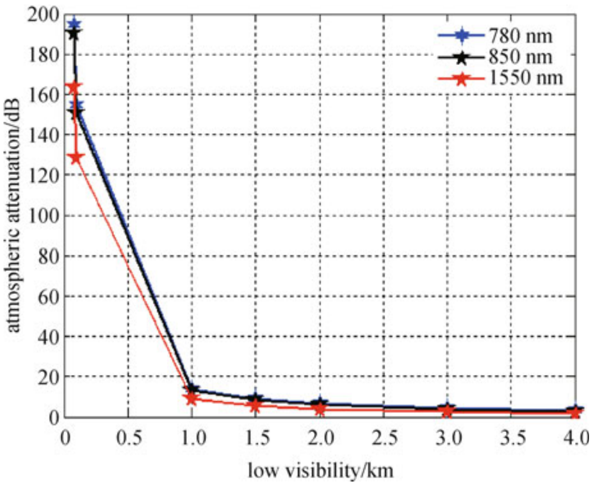

Fig. 16 Atmospheric attenuation (dB) versus low visibility (km) for Taiz city

5 Optical link budget

After illustrating the geometric loss, total attenuation, and haze effects on the FSO in Sana'a, Aden and Taiz cities, we return to the link budget of FSO systems. This section concentrates on received power versus low and average visibilities, and link range. Table 6 illustrates the main FSO link parameters. We note that all the given values in this table are presumed to calculate the received power for three cases as presented in Figs. 17 – 19.

The results in Fig. 17 show the relationship between received power for three different wavelengths and low visibility. As seen in Fig. 17, received power increases with the increment of low visibility. We note that the obtained received power at the wavelength of 1550 nm is the best as compared to other two wavelengths. For example, the received power curve for the wavelength of 1550 nm increases from – 67 dBm at the distance of 0.6 km to – 27 dBm at the distance of 5 km. However, we note that the received power is reduced for other two wavelengths of 780 and 850 nm. As shown in Fig. 18, the received power at wavelength of 1550 nm shows the best compared to other two wavelengths of 780 and 850 nm.

Figure 19 shows the received power versus the link range. As the link range between transmission and receiver increases, the received power decreases. At the distance of 0.5 km, the received power for the wavelength of 1550 nm is of – 20.3 dBm, which for the other two are of – 21.7 dBm. However, in the distance of 5 km, the received power reaches – 36 dBm for wavelength of 780 nm and – 34.1 dBm for the wavelength of 850 nm. For three study cases, the study was done to improve the efficiency of FSO systems, the wavelength of 1550 nm for three cases must be used and the distance between transmitter and receiver should be reduced.

6 Technical analyses of obtained results

In this part, we discuss the effects of scattering, atmospheric attenuation during hazy and rainy days, and the effect of atmospheric turbulence during clear days on the performance of FSO system in Yemen. This section includes an analysis and discussion about the results of these effects in Yemen in general and Sana'a, Aden and Taiz cities in particular. Table 7 presents the data of visibility obtained from Civil Aviation and Meteorology Authority (CAMA) for year 2008 [15].

6.1 Haze effect on FSO system

Depending on the data shown in Table 7, simulation results show that the fog is the main responsible factor to reduce the visibility in Yemen, where the attenuation during hazy days is induced by haze such as in Aden city or fog such as in Taiz city. The larger atmospheric attenuation in two cities during hazy days (due to fog) is about 163.5 dB in Jun., Feb. and May at the visibility of 0.05 km for wavelength of 1550 nm while for the same wavelength in Sana'a city is about 37.7 dB in Feb. at low visibility of 0.3 km.

From the previous analysis of results during hazy days,

Table 5 Results of scattering coefficient and atmospheric attenuation at low visibility for Sana'a, Aden and Taiz cities

city	wavelength/nm	scattering coefficient/km^{-1}		atmospheric attenuation/dB	
		from	to	from	to
Sana'a	780	11.37	0.45	49.4	2
	850	10.99	0.41	47.7	1.8
	1550	8.69	0.21	37.7	0.94
Aden	780	44. 8	0.45	194.4	1.95
	850	43.8	0.41	190.2	1.8
	1550	37.6	0.22	163.5	0.94
Taiz	780	44.8	0.7	194.4	3.1
	850	43.8	0.65	190.2	2.8
	1550	37.6	0.37	163.5	1.6

Table 6 Optical link budget parameters

parameters	description
wavelength (λ)	780, 850, 1550 nm
transmit power (P_{tx})	23.52 dB
beam divergence	1 mrad
visibility	5 km

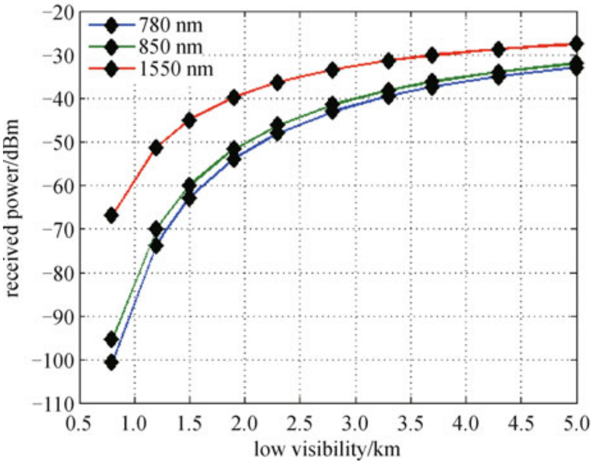

Fig. 17 Received power (dBm) versus low visibility (km)

the attenuation at low visibility is higher than attenuation at average visibility. This is because the density of haze particles at low visibility is higher than the density of particles at average visibility. The results prove that the serious challenge of FSO systems in Yemen is the fog attenuation in hazy days.

6.2 Rain effect on FSO system

From the previous analysis of rain effect on FSO system,

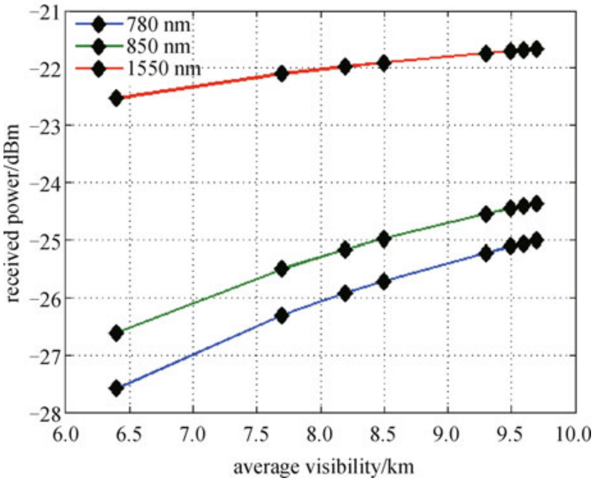

Fig. 18 Received power (dBm) versus average visibility (km)

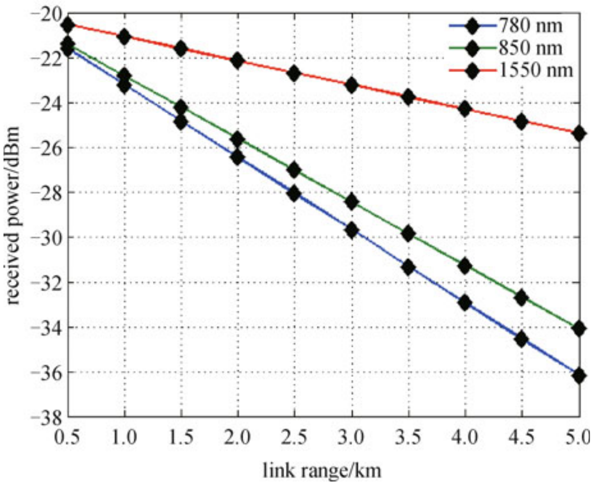

Fig. 19 Received power (dBm) versus link range (km)

Table 7 Data of visibility obtained from CAMA for year 2008

month			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
visibility/km	Sana'a	average	9.9	8	9.1	9.1	9.5	7.3	5.6	8.6	9.8	9.8	10	10
		low	5	0.3	1	2	4	0.7	0.5	2	3	2	7	6
	Aden	average	9.7	8.3	9.1	9.2	9.4	7	5.7	8	9.1	9.2	9.8	9.7
		low	6	2	5	7	3	3	1	5	3	0.05	8	7
	Taiz	average	9	8.4	9.7	9.7	9.9	8.9	8	8.8	9.9	9.5	9.3	8.9
		low	0.05	0.05	4	4	0.05	2	3	1.5	1	1.5	0.1	0.1

we found that attenuation is subject to rainfall rate and radius of raindrop. The attenuation is higher during heavy rain than those in moderate and light. Attenuation during heavy rains due to liquid contents is higher than those during moderate and light rainfalls.

The maximum attenuation during the heavy rain in Yemen is about 0.69 dB. The attenuation at the good weather conditions during hazy days (average visibility) is bigger than that during bad atmospheric conditions at the rainy days (heavy rains). From these results, we conclude that the effect of rain on the performance of FSO system in Yemen is less than those of fog and haze. Therefore, we can ignore its impact according to the results obtained previously.

6.3 Geometric loss effect on FSO system

The effect of geometric loss can be controlled and remain fixed because it does not depend on elements that change with time and place during different weather conditions. From those results, FSO system should be designed with the minimum geometric loss to improve its performance. To reduce the effect of geometric loss, the receiver's aperture should be large enough while the transmitter's aperture and the angle of laser beam divergence must be small.

6.4 Total attenuation effect in hazy and rain days

The total attenuation is determined by the atmospheric attenuation and geometric loss. As we mentioned earlier, geometric loss can be controlled, whereas atmospheric attenuation depends on link range and weather conditions. Weather conditions change with time, but we can control the link range. Therefore, in order to reduce the effect of the total attenuation on the FSO system, the geometric loss must be small and link range between transmitter and receiver should be short.

7 Conclusions

FSO is considered as alternative choice that can be employed as a reliable solution to broadband short distance applications. Nowadays, this technology is not used in Yemen. However, mobile operators are planning to use this technology to short distance links. In this paper, we demonstrated the climate effects on the performance of FSO communication system in Yemen. We studied in detail the total attenuation influencing FSO systems. These results showed that when the link range, divergence angle, and transmitter aperture were increasing, the geometric loss increased too. But, we found that geometric loss decreased with the increasing of the receiver aperture diameter. Total attenuation also increased with increasing of the distance link, low visibility, and with decreasing of the wavelength. It was also shown that the effect of rainfall on the FSO system performance was so small that we can neglect it. In general, FSO performance was bad in Taiz at the low visibility compared to that in Sana'a and Aden. However, in the average visibility, the FSO performance was effective in three cities.

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