

Multi-Channel Free Space Optical Communication Under Frequent Sand and Dust Storms

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Abstract: Free-Space Optical (FSO) is considered to be one of the key technologies for high-speed and large-capacity wireless communications. The reliability and availability of the optical path for wireless broadband communications is influenced by the local weather conditions. The countries of the Middle East including Iraq suffer from frequent Sand and Dust Storms (SDS) reach the maximum during the period (2010-2012). In the present study, optimized design was implemented to investigate the fluctuations of transmitted optical signal along the path and determining system performance. By using (OptiSystem7) software, simulation employs with Multiple-Input Multiple-Output (MIMO) technique. The obtained results show that bit error rates BER goes on decreasing when the signal to noise ratio is decreased at the beginning of 2010 then increasing the BER performance for next season's leads to the reduced received optical power due to weather turbulence effect. The results presented in this study are useful for designing a stable FSO system for dry and dusty regional environments.

Key words: Free-spaceoptics, signal attenuation, wireless communications, OptiSystem 7, atmospheric turbulence, dust storms

INTRODUCTION

Recently, demands for a high-bandwidth and higher data rate communication system carrying various services for last-mile access networks. The Free Space Optical (FSO) technology has been developed to satisfy these demands (Majumdar, 2014). Optical waves, Radio Frequency (RF) waves and acoustic waves are generally used for transition of information (Reshma and Ramesh, 2018). Due to the wider bandwidth of highest radio frequency make it enable of carrying high data rate (Adnan *et al.*, 2018). FSO is suitable for transfer of financial, legal, military or othersensitive information. For its highest security comparedto RF-transmission (Tang *et al.*, 2012). FSO communication systems have attracted a considerable attention as efficient solution due to their advantages. The main challenge in such system is losing the Line of Sight (LoS) due to scatter of the light photons by different atmospheric aerosols. In some countries the Sand and Dust Storms (SDS) reduce visibility to near zero where, visibility improving away from the source. Unfortunately, Iraq is one of those countries where (SDS) occur most frequently in the summer, though severe storms may also occur from

spring through autumn (Kadhim *et al.*, 2016). The dust storms frequency rises in region, especially in dry areas with poor rain. Depending on location it is not unusual for Iraq to encounter (20-50) days of blowing sand and dust each year (Sissakian *et al.*, 2013). Dust can persist for days. When winds drop beneath the speed needed to carry the particles the dust settled down. Also, some amount of dust haze will persist for long time. (SDS) caused by strong winds blowing over loose soil or sand, picking up so much of that material that visibility is greatly reduced during these storms as shown in Fig. 1 (Anonymous, 2003, 2013). This attenuation effect can be reduced by manipulating several parameters such as narrow beam divergence, small transmitter and larger area receiver, longer wavelength medium and minimizing the overall Bit Error Rate (BER) (Anis *et al.*, 2017; Khaleelahmed *et al.*, 2018). In present study, the effect of 10 dust storms struck Baghdad City during the period (2010-2012) on FSO System employs with Multiple-Input Multiple-Out-put (MIMO) technique is investigated using (OptiSystem 7) software for understanding and help designing effective and reliable FSO networks for dry and dusty regional environments.

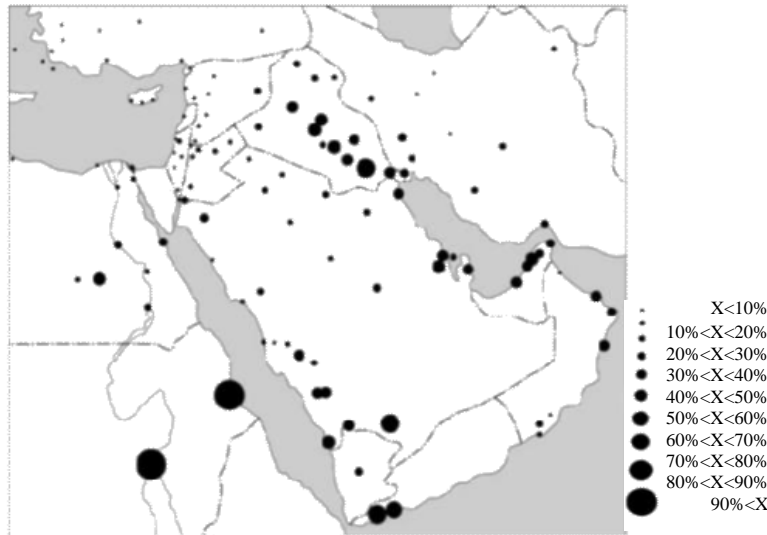


Fig. 1: Spatial distribution of visibility reduction in (%) of the time. Circles size's are proportional to percentage of visibility reduction (Akbari, 2011; Sissakian *et al.*, 2013)

MATERIALS AND METHODS

FSO Model and simulation: In order to compute attenuations caused by SDS, theoretical approaches based on microphysical models is used. 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 (Willebrand and Ghuman, 2011):

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

Where:

- $\gamma(\lambda)$ = The total attenuation coefficient (m^{-1})
- PR = The received optical power at a distance (L)
- PT = The transmitted optical power at the optical source
- $\tau(\lambda, L)$ = The transmittance of the atmosphere at wavelength (λ)

By neglect the attenuation contribution by molecular and aerosol absorption as it is very small. Thus, attenuation due to aerosol scattering $\beta_a(\lambda)$ is given by:

$$\gamma(\lambda) = \beta_a(\lambda) \tag{2}$$

The attenuation resulting by scattering can be calculated due to visibility range estimation by the following Eq. 3 (Kim *et al.*, 2001):

$$\gamma(\lambda) \approx \beta_a \approx \frac{17.35}{v} \left(\frac{\lambda}{550} \right)^{-q} \tag{3}$$

Where:

- v = Visibility range in km
- λ = Transmission wavelength in nm
- $\gamma(\lambda)$ = The total extinction coefficient for SDS
- q = The size distribution coefficient of scattering related to size distribution of the dusts

The parameter q in Eq. 3 depends on the visibility distance range and q is the particle size distribution for Kruse Model is given by the following equation (Kruse *et al.*, 1962):

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

In addition, to design and simulate FSO communication system based on Multiple-Input Multiple-Output (MIMO) technique for analysis its performances under SDS. The visibility (m) data used in this study provided by Iraqi meteorological organization and seismology (Baghdad Station) (AL-Salihi and Mohammed, 2015). The LoS propagation path can range from hundreds of meters up to tens of km (Kartalopoulos, 2011). In this adaptive system, variable number of transmitters and receivers are adopted to mitigate weather turbulence and to achieve maximum capacity gain for the transmitted power. By using (OptiSystem Version 7.0) software, the adaptive FSO systems have been designed.

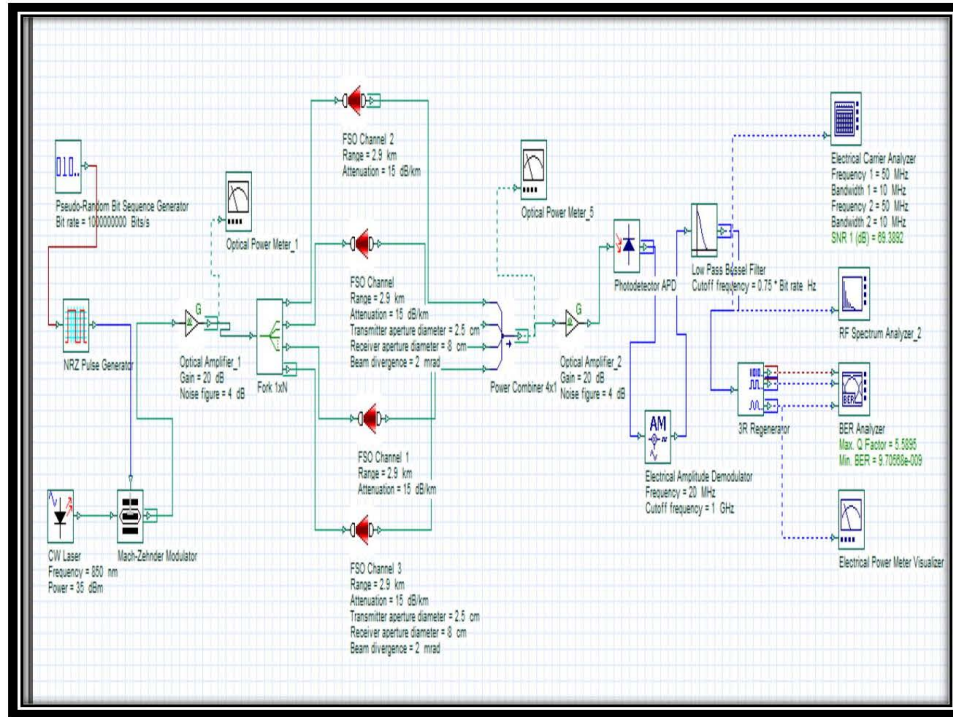


Fig. 2: Simulation layout of four channels FSO system

This system is used wavelength of 850 nm. The transmitter includes Pseudo Random Bit Sequence (PRBS) generator, Non-Return to Zero (NRZ) pulse generator, laser source and Mach Zehnder Modulator (MZM). Moreover, the data generated by the PRBS generator at 2.5 Gbps are encoded and the light modulated using MZM. The laser source acts as the carrier pass through the atmospheric channels in free space provided channel capacity of approximately 40 dBm. The apertures of the transmitter and receiver are set to 2 and 10 cm and the beam divergence is 2 mrad. In order to study all the loss effect on the main link of free space optical communication system resulting by scattering under SDS. In simulation design shown in Fig. 2, (4TX/4 RX) four channels are used as MIMO link to enhance the received signal for the purpose of improving the efficiency of the main system. The attenuation value is set as 0.2 dB/km (for clear weather). The optical signals were received by Avalanche Photo Diode (APD). Finally, BER analyzer automatically calculates the BER value and Signal to Noise Ratio (SNR).

RESULTS AND DISCUSSION

The transmitted beams in multiple input-multiple output FSO system are adopted to mitigate weather for

achieving maximum capacity gain. Both signal SNR and BER are used to evaluate the quality and maximum capacity of the receiving power. The simulation parameters are utilized to achieve robustness of the system as shown in Table 1. The numerical analysis based on SDS struck Baghdad city during the period (2010-2012) which is shown in Table 2 (AL-Salihi and Mohammed, 2015). Table 3 shows the numerical results of the attenuation, Signal to Noise Ratio (SNR) and bit error rate under different seasons. Effects of SDS also result in beam attenuation due to photon absorption and scattering in agreement with (Gagliardi and Karp, 1995). Notice that the numerical results of the visibility effect on signal attenuation present in Fig. 3. Where, they inversely proportional in the beginning of 2010 followed with stable fluctuations at the next seasons, these results corresponding with (Rashed and Tabbour, 2014). As illustrated in Table 3, the values of BER goes on increasing when the SNR is increased in the beginning of 2010 then the BER performance slightly fluctuated and SNR increased in compared with the next seasons under the same operating conditions. These results indicated that MIMO System provides better BER performance for wide range of aerosol optical depth change reach to 0.4.

Table 1: System simulation parameters

parameter	Values
Transmitter optical power (dBm)	40
Transmitter divergence angle (mrad)	2
Transmitter efficiency	0.5
Receiver sensitivity (dBm)	-20
Receiver diameter (cm)	8
Receiver efficiency	0.5

Table 2: Meteorological variables for the SDS events during the period (2010-2012)

Date of storms	Visibility change (km)	Aerosol optical depth change
7-8.6.2010	1.917	0.10
16.3.2010	5.209	0.32
19.9.2010	4.600	0.40
20-21.7.2010	3.455	0.32
23-24.6.2010	5.292	0.32
13.5.2011	3.388	0.40
13.10.2011	4.255	0.32
27.7.2011	3.568	0.32
12.6.2012	3.121	0.16
19.4.2012	0.634	0

Table 3: Communication system parameters obtained through simulation

Attenuation values (dB/km)	SNR(dB)	BER
7.503	98.1375	9.70E-09
2.761	112.521	9.70E-09
3.127	111.418	9.70E-09
4.163	108.291	9.70E-09
2.718	112.651	9.70E-09
4.245	108.044	9.70E-09
3.406	110.577	9.70E-09
4.011	108.751	9.70E-09
4.609	106.943	9.70E-09
24.66	19.9951	2.83E-07

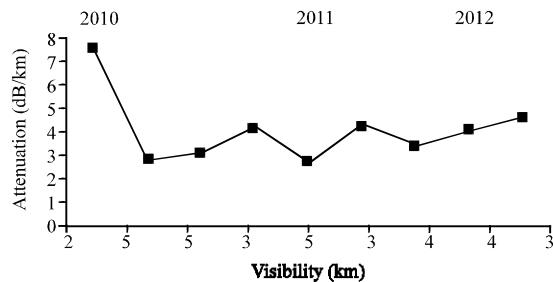


Fig. 3: Channel visibility versus optical power attenuation

CONCLUSION

In this study, we discussed SDS effect on the optical wireless communication for different seasons in Iraq. Using multiple input-multiple output FSO system was useful in determining maximum capacity of the receiving power. It is shown that the BER increased in the first season as SNR increased then the BER performance have indicated stable fluctuation for next seasons. The stable bit error probability of such systems is near from satisfying the typical targets for FSO link. Moreover, it is

observed that MIMO system provides better BER performance for higher aerosol optical depth change for dry and dusty regional environments.

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