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Realization of free space optics with OFDM under atmospheric turbulence

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ABSTRACT

Free space optics (FSO) technology provides a promising solution for future broadband networks, offering high data transmission compared to RF technology. This work is focused on investigating the performance of an FSO system with OFDM and QAM. A 10 Gbps data stream is transmitted using a 4-level QAM sequence through the FSO system under different atmospheric conditions. Results indicate that the integration of SOA prolongs the maximum achievable distance with acceptable SNR to 185 km under clear weather conditions whereas under atmospheric fog, the maximum distance is extended to 2.5 km.

1. Introduction

The growth of internet traffic in conjunction with an increase in the number and range of new services has placed pressure on radio networks operating on low-speed infrastructure. Free space optics (FSO) has the combined features of prevalent telecommunication technologies, i.e. wireless and fiber optics. FSO communication has attracted significant attention recently in high data rate wireless links and provided the essential combination of qualities required to bring traffic to the optical fiber backbone. FSO technology is also a promising solution for the "last mile" problem. FSO networks can be used as information bridges between nodes in local area networks and wireless local loops [1]. In addition, FSO provides secure transmission because of negligible interception using point-to-point laser signals. High capacity, low power consumption, license-free and low deployment costs are some of the merits of FSO [2,3]. FSO has similar working principles as fiber optic communication, the main difference being the use of the atmosphere instead of optical fiber as the channel. An FSO network can be implemented as a point-to-point, mesh or point to multipoint architecture [4]. Low power infrared beams, not harmful to the human eye, can transmit data through the air between links comprising distance of few meters to several kilometers [5]. FSO provides good solutions for broadband networks, especially in geographical areas where optical fiber deployment is not feasible but there are some performance limitations. The most dominant limiting factors are atmospheric conditions such as fog, dust, snow or rain that debilitates the transmission path and may close down the network. Thus, in the design of FSO systems, these atmospheric parameters must be considered [6]. The link equation for free space optics [7] is

$$P_{\text{Recieved}} = P_{\text{Transmitted}} \frac{d_R^2}{(d_T + \theta R)^2} 10^{-\alpha R/10} \tag{1}$$

where d_R defines the receiver aperture diameter, d_T is the transmitter aperture diameter, θ is the beam divergence, R is the range and α is the atmospheric attenuation. In FSO links, multipath fading is another limiting factor.

Significant effort is imperative for reducing multipath fading due to atmospheric turbulence. OFDM has immense potential for mitigating multipath fading due to atmospheric turbulences in FSO as data is distributed over a large no of orthogonal carriers that are sufficiently spaced at narrow frequencies with overlapping bands. The use of fast Fourier transform (FFT) provides orthogonality to the subcarriers, preventing the demodulators from seeing frequencies other than their own. The application of OFDM offers higher data capacity, secure transmission, high speed and smooth upgrade [8]. The rest of the paper is organized into following sections: Section 2 describes the simulation setup for OFDM–SOA system and Section 3 describes the result and discussion. The paper is concluded in Section 4.

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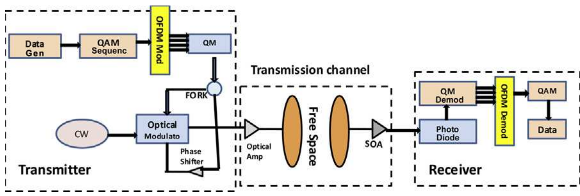

Fig. 1. Block diagram of proposed FSO network.

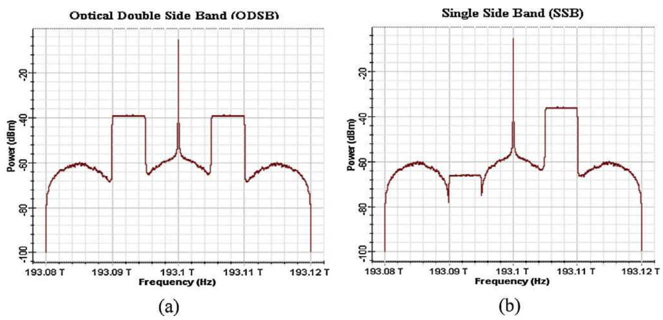

Fig. 2. Generation of modulation format. (a) ODSB. (b) OSSB.

2. System description

The proposed OFDM–FSO system is modeled using OptiSystem^{TM} from Optiwave Corp. 10 Gbps data is generated through 4-level QAM sequence generator using 2 bits per symbol. The QAM data signal is modulated by an OFDM modulator using 512 subcarriers, 1024 FFT and 32 cyclic prefix code before being modulated at 7.5 GHz using a QAM modulator as shown in Fig. 1. This QAM signal is transmitted over free space by means of a continuous wave (CW) laser having a wavelength of 193.1 THz and power of 0 dBm.

The FSO network consists of pre- and post-amplification in which SOA is incorporated for post-amplification. At the base station, the OFDM signals are retrieved using a PIN photodetector and fed to the QM demodulator followed by the OFDM demodulator and QAM sequence decoder in order to recover the 10 Gbps data successfully.

The optical modulation formats are shown in Fig. 2. OSSB is generated by using a phase shift in the optical modulator.

3. Results and discussion

The results are presented in this section. Fig. 3 depicts the measurement of SNR and received power for ODSB and OSSB modulation formats under clear weather condition by considering attenuation of 0.11 dB/Km. It has been observed that after 20 km, an improvement of 3.2 dB is measured in the case of ODSB. The OSSB technique suffers more severely from fading. After 60 km, both the OSSB and ODSB perform equally well.

The total received power after 20 km is measured as −51.46 dBm and −54.64 dBm for ODSB and OSSB respectively. With the incorporation of SOA, the FSO link under clear weather conditions prolongs to 180 km with acceptable SNR and BER. Fig. 4 depicts the measurement of SNR and total received power under different atmospheric weather conditions. The typical values of attenuation with corresponding visibilities is considered as 4 dB for Haze,

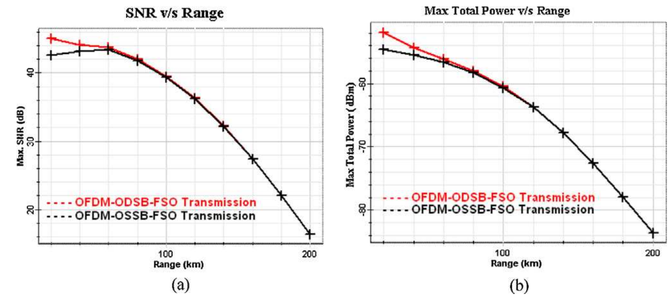

Fig. 3. Evaluation of (a) SNR vs. range. (b) Total received power vs. range under clear weather conditions.

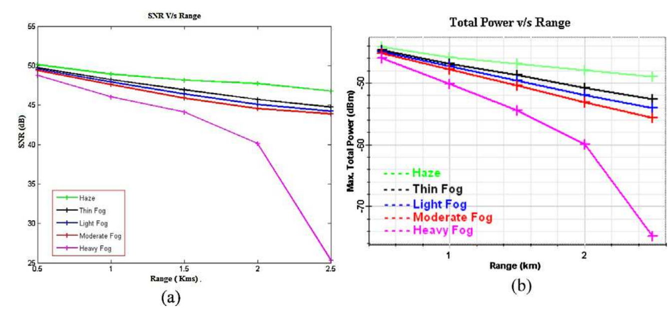

Fig. 4. Evaluation of (a) SNR vs. range. (b) Total power vs. range under different atmospheric conditions.

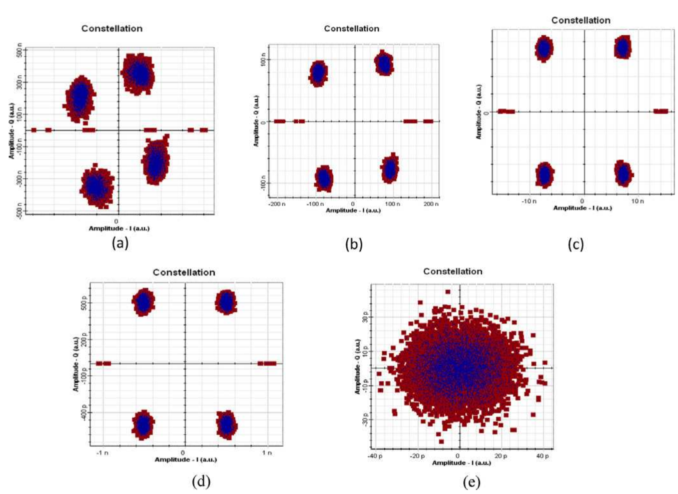

Fig. 5. Constellation diagram after 3 km FSO transmission link under different atmospheric conditions. (a) Haze. (b) Thin fog. (c) Light fog. (d) Moderate fog. (e) Heavy fog.

Table 1
Evaluation of SNR and total power under different atmospheric conditions.

Range (km)	Haze		Thin fog		Light fog		Moderate fog		Heavy fog	
	SNR (dB)	Power (dBm)	SNR (dB)	Power (dBm)	SNR (dB)	Power (dBm)	SNR (dB)	Power (dBm)	SNR (dB)	Power (dBm)
0.5	50.11	−44.13	49.70	−44.67	49.54	−44.89	49.38	−45.10	48.75	−45.99
1	48.91	−45.76	48.21	−46.79	47.90	−47.24	47.58	−47.72	46.02	−50.15
1.5	48.14	−46.89	46.91	−48.73	46.38	−49.56	45.85	−50.43	44.10	−54.37
2	47.73	−47.94	45.69	−50.71	45.05	−51.89	44.52	−53.06	40.11	−59.88
2.5	46.76	−48.97	44.71	−52.60	44.19	−54.04	43.86	−55.54	25.33	−74.75

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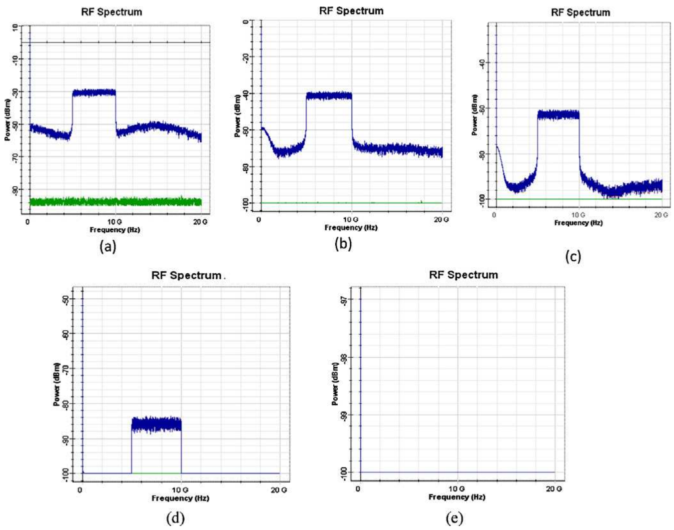

Fig. 6. RF spectrum after 3 km FSO transmission link under different atmospheric conditions. (a) Haze. (b) Thin fog. (c) Light fog. (d) Moderate fog. (e) Heavy fog.

9 dB/km for thin fog, 13 dB/km for light fog, 16 dB/km for thick fog and 22 dB/km for heavy fog [9,10].

Table 1 illustrates the value for SNR and total power for different ranges of FSO transmission link under all atmospheric conditions.

The constellation diagrams of the proposed OFDM–FSO– system under different atmospheric conditions are shown in Fig. 5. It is reported that the signal strength decreases as the atmospheric attenuation increases.

It is observed that the RF power decreases as the atmospheric conditions vary from low attenuation to higher attenuation, i.e. from haze to heavy fog. The power of the RF spectrum is computed as −30 dBm for haze, −40 dBm for thin fog, −60 dBm for light fog, −85 dBm for moderate fog and −100 dBm for heavy fog. It is also reported from the constellation diagram Fig. 5(e) and RF spectrum Fig. 6(e) that the FSO link cannot prolong to 3 km under heavy fog condition.

4. Conclusion

In this work, a novel system for 10 Gbps OFDM based on FSO is designed with the integration of the semiconductor optical amplifier (SOA). From our results, it is concluded that with the use of pre- and post-amplification technique, the FSO system will prolong to 185 km under clear weather conditions with acceptable SNR and received power. When the atmospheric attenuation is increased and reaches to heavy fog conditions, then the achievable distance is extended to 2.5 km with acceptable SNR and BER.

References

[1] B. Binder, P. Yu, J. Shapiro, J. Bounds, An atmospheric optical ring network, IEEE Trans. Commun. 38 (January (1)) (1990) 74–81.
[2] H. Willebrand, B. Ghuman, Free Space Optics: Enabling Optical Connectivity in Today's Networks, Sams, Indianapolis, IN, 2002.
[3] L. Andrews, R. Phillips, C. Hopen, Laser Beam Scintillation with Applications, SPIE, Bellingham, WA, 2001.
[4] V.W.S. Chan, Free-space optical communications, J. Lightw. Technol. 24 (12) (2006) 4750–4762.
[5] H.A. Willebrand, B.S. Ghuman, Fiber optics without fiber, IEEE Spectrum 38 (8) (2001) 40–45.
[6] Z. Jia, Q. Zhu, F. Ao, Atmospheric attenuation analysis in the FSO link, in: International Technology on Communication Technology (ICCT), 2006, pp. 1–4.
[7] S. Bloom, E. Korevaar, J. Schuster, H. Willebrand, Understanding the performance of free-space optics, J. Opt. Networking June (2) (6) (2003) 178–200.
[8] Hamed Al Raweshidy, Shozo Komaki, Radio Over Fiber Technologies for Mobile Communications Networks, Artech House, London, 2002.
[9] E.J. McCartney, Optics of the Atmosphere, Wiley, New York, 1969.
[10] I. Kim, B. McArthur, E. Korevaar, Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications, Proc. SPIE 4214 (2000) 26–37 (Optical Wireless Communications III, edited by Eric J. Korevaar).

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