Enhancing performance of WDM-RoFSO communication system utilizing dual channel technique for 5G applications

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Abstract
In this work, the performance of wavelength division multiplexing based radio over free space optics (WDM-RoFSO) communication system is investigated utilizing OptiSystem 0.7 software. Four weather conditions are adopted in this paper, namely, clear, haze, rain and fog with attenuation losses of 0.2 dB/km, 2.3 dB/km, 4.3 dB/km and 8 dB/km, respectively. In addition, a high radio frequency of 30 GHz with high bit rate of 160 Gbps is modulated and carried on optical signal for fifth generation (5G) applications. The dual channel technique is employed in order to enhance the performance parameters of proposed WDM-RoFSO communication system. The enhancement in the link range is about; 46.1%, 35%, 29.4% and 25.9% for clear, haze, rain and fog, respectively.

Keywords Dual channel technique · Radio over free space optics · Wavelength division multiplexing

1 Introduction

The 5G communication systems will change the rules of the game through high speed and great effectiveness in various areas of modern life, for example in; internet of things, healthcare, manufacturing, data analytic, disaster management, utilities observing, as well as e-learning, video conferences, and marketing, especially during the period of the COVID-19 pandemic (Amphawan et al. 2020; Singh et al. 2021). Although with these features, the 5G networks faces several challenges, as listed in the following. The increased capacity and data rates promised by 5G require more wide spectrum and efficient technologies, beyond what is currently employed in 3G and 4G systems. Therefore, embedding radio frequencies on an optical signal and creating a radio-optical system (RoF or RoFSO) which represents a promising solution to the bandwidth problem as well as the crowding and frequency allocation concerns. In this context, RoFSO system offer many features such
as high data rates, high capacity, free of spectrum licensing, rapid and simple implementa-
tion, and robustness to electromagnetic interference. Other advantage of RoFSO links
include lightweight equipment, last mile access, low power consumption, and secure trans-
mision for WLAN link.

Furthermore, RoFSO systems are cost-effective since the central base station shares
the majority of the expensive hardware for signal processing stages such as handoff, cod-
ing–decoding, modulation–demodulation, frequency up- and down-conversion, and mul-
tiplexing demultiplexing (Balasaraswathi et al. 2020). However, there are two main chal-
lenges facing the RoFSO system desingers, namely, the limitation in the communication
capacity due to high distortion associated with combined high radio frequencies of 5G
(24–300 GHz) with the optical carrier and the link range limitation accompanied by atmos-
pheric turbulence (Al et al. 2020; Singh and Malhotra 2020).

Several approaches were produced to solve the capacity issue, such as incorporating
hybrid mode division multiplexing and polarization division multiplexing to provide 40
Gbps of data converted to a 40 GHz radio signal (Chaudhary et al. 2021). In addition, the
link range was extended using a hybrid orthogonal frequency division multiplexing-based
RoFSO with a bandwidth of 10 Gbps-10 GHz (Kuppusamy et al. 2020). In this paper, the
capacity is increased via WDM system to 160 Gbps via 16-channels each carrying 10
Gbps, and the link range is increased by 46.1%, 35%, 29.4%, and 25.9%, respectively, for
clear, haze, rain, and fog, using the dual-channel FSO.

1.1 Paper contribution

This paper contributes in the field of the RoFSO as follows:

1. Using high radio frequency of 30 GHz as well as high bit rate of 160 Gbps with con-
ventional modulation format can be considered a challenge to the field of RoFSO. This
improving qualified the proposed design to apply in 5G applications.
2. Using the dual channel technique to enhance the proposed system performance.

2 Simulation design

The proposed 16 × 10 Gbps WDM-RoFSO communication system is designed and simu-
lated by OptiSystem 7 software utilizing dual FSO channel as illustrated in Fig. 1. The RF
of 30 GHz is placed on 16-channels via optical Mach–Zehnder modulator. The operating
wavelength of the proposed WDM is ranging from 1550 to 1562 nm with a channel spac-
ing of 0.8 nm. As any conventional communication system, the proposed system consists
of three main parts, namely: the transmitter, optical channel, and receiver as illustrated in
Fig. 1a.

The transmitter consists of two parts as depicted in Fig. 1b; CW-laser and RF source.
The RF source consists of a pseudo random bit sequence generator (PRBS) and a non-
return to zero pulse generator (NRZ). Both PRBS and NRZ are combined into a sine wave
generator by an electrical multiplier component. Then the radio signal is modulated over
the CW-laser by a Mach–Zehnder modulator, resulting in an RF carried on optical signal.
Dual FSO channel are used to enhance the proposed system performance. The optical signal is received and demodulated by the receiver section, which consists of a Gaussian optical filter followed by a PIN photodiode, band pass electrical filter and 3R-regenerator as illustrated in Fig. 1c. The design parameters of the proposed system are depicted in Table 1.

3 Results and discussion

This part is devoted to review and discuss the obtained results, which can be divided into three parts: investigated the WDM-RoFSO at high radio frequency of 30 GHz, then, employing the dual channel technique to enhance the performance of the proposed system.

Fig. 1 The proposed WDM-RoFSO communication system

Fig. 2 The results of the clear weather (0.2 dB/km), the obtained link distance about 1.3 km for single FSO channel a Q-Factor versus link distance, b BER versus link distance
Fig. 3  The results of the hazy weather (2.3 dB/km), the obtained link distance about 1 km for single FSO channel  

- **a** Q-Factor versus link distance,  
- **b** BER versus link distance

Fig. 4  The results of the rainy weather (4.3 dB/km), the obtained link distance about 0.85 km for single FSO channel  

- **a** Q-Factor versus link distance,  
- **b** BER versus link distance

Fig. 5  The results of the foggy weather (8 dB/km), the obtained link distance about 0.675 km for single FSO channel  

- **a** Q-Factor versus link distance,  
- **b** BER versus link distance
and finally, the comparison between the single and dual FSO channel. The results of proposed WDM-RoFSO utilizing single FSO channel are illustrated in Figs. 2, 3, 4 and 5 for weather condition clear, haze, rain and fog, respectively.

The (quality factor of 6 or BER of 10e−9) is adopted as a communication condition in this work. According to the results, the communication distance is decreased as the atmospheric loss is increased, this agree with results in the literature (Yaseen et al. 2020, 2021; Abdulsatar et al. 2021). The maximum obtained range is about 1.3 km with the clear weather, the link distance degraded with the increasing in the attenuation to reaches to 0.675 km at foggy weather.

In order to enhance the performance of the proposed WDM-RoFSO a dual FSO channel are used and the obtained results are illustrated in Figs. 6, 7, 8 and 9 for wheather condition of clear, haze, rain and fog, respectively. The maximum obtained range is about 1.9 km with the clear weather, the link distance degraded with the

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Fig. 6 The results of the clear weather (0.2 dB/km), the obtained link distance about 1.9 km for dual FSO channel a Q-Factor versus link distance, b BER versus link distance

Fig. 7 The results of the hazy weather (2.3 dB/km), the obtained link distance about 1.35 km for dual FSO channel a Q-Factor versus link distance, b BER versus link distance
Increasing in the attenuation to reaches to 0.85 km at foggy weather. Finally, to clarify the improvement in the proposed system, the performance of S-FSO and D-FSO are redrawn at 1562 nm as illustrated in Fig. 10a–d for weather condition of clear, haze, rain and fog, respectively. The dual channels produce an enhancement in the link range about 46.1% at clear weather, 35% at haze, 29.4% at rain and 25.9% at fog as illustrated in Table 2.

Fig. 8 The results of the rainy weather (4.3 dB/km), the obtained link distance about 1.1 km for dual FSO channel a Q-Factor versus link distance, b BER versus link distance

Fig. 9 The results of the foggy weather (8 dB/km), the obtained link distance about 0.85 km for dual FSO channel a Q-Factor versus link distance, b BER versus link distance
In addition, the eye diagram for the WDM-RoFSO is compared at several link ranges namely, 1.9 km, 1.35 km, 1.1 km and 0.85 km under weather conditions of clear, haze, rain and fog, respectively, for both of single and dual FSO channel as depicted in Fig. 11.
| Items                  | Description                                                                 |
|------------------------|------------------------------------------------------------------------------|
| Transmitter assembly   | CW laser Wavelength: 1550–1562 nm, steps 0.8 nm                               |
|                        | Max. power 10 dBm, linewidth: 10 MHz                                          |
|                        | Bit rate = 16 × 10 Gb/s                                                       |
|                        | Pseudo-random bit sequence generator                                           |
|                        | NRZ pulse generator                                                           |
|                        | Sine generator Frequency = 30 GHz                                               |
|                        | Phase = 90°                                                                  |
|                        | Mach–Zehnder Modulator                                                        |
|                        | Electrical multiplier                                                         |
| FSO channel            | Range km 1–10                                                                 |
|                        | Atmospheric attenuation Clear = 0.2 dB/km, haze = 2.3 dB/km, rain = 4.3 dB/km |
|                        | fog = 8 dB/km                                                                 |
|                        | Transmitter diameter 15 cm                                                    |
|                        | Receiver diameter 20 cm                                                       |
|                        | Beam divergence 1 mrad                                                         |
| Receiver assembly      | Gaussian optical filter                                                       |
|                        | Photodetector PIN                                                             |
|                        | Band pass Gaussian filter                                                     |
|                        | 3R regenerator                                                               |
|                        | BER analyzer                                                                 |

Table 1 The simulation design parameters for the proposed WDM-RoFSO communication system
The performance of the proposed WDM-RoFSO is enhanced via dual FSO channel. A 16 channels within 10 Gbps of bit rate were adopted in this work in order to achieve a high capacity of 160 Gbps. The proposed system with this capacity suffered from limitation in terms of link range. A duale channel technique is employed to enhance the link range and reduce the noise effect due to modulate the high radio frequency of 30 GHz with the optical signal. The enhancement in the link range reduced from 46.1% at clear weather to 25.9% at fog. This can be attributed to the fact that channel doubling leads to a doubling of the received power, and this power will be reduced in bad weather conditions due to high atmospheric attenuation. In addition, the proposed WDM-RoFSO is considered efficient for the fifth generation applications, because it operates at a high frequency of 30 GHz.
| Weather Condition | Distance (km) | WDM–RoFSO at S–FSO | WDM–RoFSO at D–FSO |
|-------------------|-------------|-------------------|-------------------|
| Clear             | 0.2 dB/km   | ![Eye Diagram](image) | ![Eye Diagram](image) |
|                   | 1.9 km      | ![Eye Diagram](image) | ![Eye Diagram](image) |
| Haze              | 2.3 dB/km   | ![Eye Diagram](image) | ![Eye Diagram](image) |
|                   | 1.35 km     | ![Eye Diagram](image) | ![Eye Diagram](image) |
| Rain              | 4.3 dB/km   | ![Eye Diagram](image) | ![Eye Diagram](image) |
|                   | 1.1 km      | ![Eye Diagram](image) | ![Eye Diagram](image) |
| Fog               | 8 dB/km     | ![Eye Diagram](image) | ![Eye Diagram](image) |
|                   | 0.85 km     | ![Eye Diagram](image) | ![Eye Diagram](image) |

Fig. 11 The eye diagram for the WDM-RoFSO is compared at several link ranges namely, 1.9 km, 1.35 km, 1.1 km and 0.85 km under weather conditions of clear, haze, rain and fog, respectively, for both of single and dual FSO channel.
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Declarations

Competing interests  The authors have not disclosed any competing interests.

References

Abdulsatar, S.M., Saleh, M.A., Abass, A.K., Ali, M.H., Yaseen, M.A.: Bidirectional hybrid optical communication system based on wavelength division multiplexing for outdoor applications. Opt. Quantum Electron. 53(10), 597 (2021)
Ali, M.A.A., Adnan, S.A., Al-Saeedi, S.A.: Transporting 8 × 10 Gbps WDM Ro-FSO under various weather conditions. J. Opt. Commun. 41, 99–105 (2020)
Amphawan, A., Chaudhary, S., Neo, T.-K., Kakavand, M., Dabbagh, M.: Radio-over-free space optical space division multiplexing system using 3-core photonic crystal fiber mode group multiplexers. Wirel. Netw. 27, 211–225 (2020)
Balasaraswathi, M., Singh, M., Malhotra, J., Dhasarathan, V.: A high-speed radio-over-free-space optics link using wavelength division multiplexing-mode division multiplexing-multibeam technique. Comput. Electr. Eng. 87, 106779 (2020)
Chaudhary, S., Wuttisittikulkij, L., Nebhen, J., Tang, X.: Hybrid MDM-PDM based Ro-FSO system for broadband services by incorporating donut modes under diverse weather conditions. Front. Phys. 9, 756232 (2021)
Kuppusamy, P.G., Rajkumar, K., Maheswar, R., Rani, S.S., Amiri, I.S.: A long-reach radio over free space optics (Ro-FSO) system using hybrid orthogonal frequency division multiplexing (OFDM)-multibeam concept with enhanced detection. J. Opt. Commun. 41, 1–7 (2020)
Singh, M., Malhotra, J.: Performance comparison of different modulation schemes in high-speed mdm based radio over FSO transmission link under the effect of atmospheric turbulence using aperture averaging. Wirel. Pers. Commun. 111, 825–842 (2020)
Singh, M., Pottoo, S.N., Malhotra, J., Grover, A., Aly, M.H.: Millimeter-wave hybrid OFDM-MDM radio over free space optical transceiver for 5G services in desert. Alex. Eng. J. 60, 4275–4285 (2021)
Yaseen, M.A., Abass, A.K., Abdulsatar, S.M.: Enhancing of multiwavelength free space optical communication system via optimizing the transceiver design parameters. Opt. Quant. Electron. 52(8), 383 (2020)
Yaseen, M.A., Abass, A.K., Abdulsatar, S.M.: Improving of wavelength division multiplexing based on free space optical communication via power comparative system. Wirel. Pers. Commun. 119(4), 381–391 (2021)

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