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Performance Analysis of a RoFSO Link for 5G Networks Under Adverse Weather Conditions

Abstract. *5G systems are about to be democratized. Radio over Free Space Optics (RoFSO) is a promising technology which could back the rapid deployment of the 5G networks owing to its high data carrying capacity and hazzle free installation capabilities. The RoFSO links use the atmospheric channel for communication and are susceptible to performance degradation due to various environmental factors. In this work, a 26 GHz RoFSO link delivering 10 Gbps is designed and its bit error rate performance is analyzed using Kruze atmospheric model under different climatic conditions like rain, fog, dust, and haze.*

Streszczenie. *Dzięki sieci 5G możliwy jest rozwój takich technologii jak Radio over Free Space Optoics RoFSO. To radio łączy komunikację bezprzewodową z możliwością eliminacji zakłóceń. Opisano system o częstotliwości 26 GHz i przepustowości 10 Gbps. (* ***Analiza możliwości systemu RoFSO w sieci 5G dla różnych warunków pogodowych****)*

Keywords: 5G Networks, Free Space Optics, Optical Wireless Communication, Radio over Fiber.
Słowa kluczowe: system RoFSO – Radio over Free Space Optics, sieć 5G.

Introduction

Optical networks are expected to be the backhaul of the soon to be deployed 5G networks as in the case of existing 4G systems. Unlike the 4G, 5G networks are expected to deliver a wide variety of services at high speeds [1]. The ever-increasing bandwidth hunger of the population is expected to be quenched by the high-speed data carrying capacity of the fifth-generation networks, at least for a period. The delay in implementation of the systems is mainly due to the lack of consensus among the authorities and researchers in adopting the right technologies and standards. Though multiple competent devices and network topologies are available, it is difficult to elect the most apt one.

Radio over Fiber (RoF) is a promising network architecture capable of delivering high speed data and other services to the end users. RoF has a hybrid structure consisting of fiber and wireless links. Apart from the inherent advantages of employing optical fibers for communication, RoF draws its advantages by the direct modulation of radio frequency (RF) signals on to light and the transport of the same through the fiber network. RoF networks are transparent in nature and can be used for transport of any analog signals which makes it the perfect candidate for 5G systems where multiple radio frequency bands are to be transmitted simultaneously to serve the wide variety of services through the single network [2]. The use of high frequency bands for high data rate services decreases the cell size and thereby increases the number of base stations or radio access points (RAPs). But the omission of baseband to RF modulation, demodulation processes and associated devices at each base station makes the base stations/RAPs functionally simple and the deployment of the system economically feasible.

In RoF systems, optical fibers are employed to carry the RF modulated optical signals. But as optical fiber is a wired communication medium, in certain scenarios, it is difficult to establish RoF links where the laying of optical fiber is practically impossible. Radio over Free Space Optics (RoFSO) communication is a modified version of the basic RoF network where free space or open atmospheric channel is used for communication. This free space link can be used as an alternative to the fiber link in the RoF or a combination of fiber and atmospheric channel also can be used as per requirement. The benefits like high speed, premium bandwidth, no licensing, impunity to radio interference and information security makes it an elite solution for 5G [3]. The basic architecture of a typical RoFSO communication system is illustrated in Fig. 1.

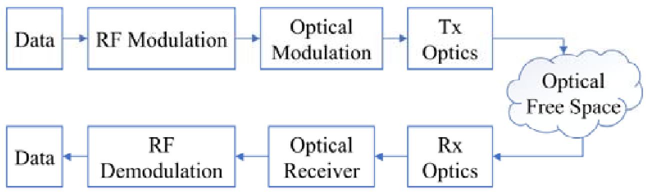

Fig.1. Basic Architecture of a Radio over Free Space Optical Communication System

The major applications of such RoFSO systems will be in situations where emplacing optical fiber is practically difficult. It also enables fast deployment as no trenching or laying of optical fiber is required. Setting up a laser transmitter and receiver in line of sight (LoS) is enough for the basic configuration which makes it apt for inter-building communications for Metropolitan Area Networks, Local Area Networks, cellular backhaul for remote locations and fiber optic backups. Similar to RoF systems, RoFSO systems also provides high data carrying capacities. The data carrying capacity can be retained, as light itself is used for free space links. The possible bottleneck on data transfer may be due to the electro-optic and opto-electric conversion devices used as transmitters and receivers in the link. However, there are certain environmental factors also that may arise between the transmitter and receiver which could affect the performance of the link.

A lot of research is carried out to model and thereby to study the transmission characteristics of the atmospheric channel. Effect of various parameters like optical wavelength [4], optical power, modulation schemes [5], multiple input multiple output (MIMO) [6] schemes were studied. The effect of external factors such as absorption, scattering, and atmospheric turbulence [3] were mentioned as the adverse factors which affects the performance severely. Hosam Abd Elrazek Mohamed Ali et al. in [6] demonstrated the effect of various climatic conditions on an FSO link performance. They have studied the free space communication performance under environmental factors such as haze, snow, rain, fog, and dust using the Kruze model, which is directly adopted in this work. The analysis done in [6] is extended to the proposed 5G RoFSO link with detailed analysis of link bit error rate performance. The link performance is analyzed using Optisystem simulation tool.

The rest of the article is arranged as follows: section 2 discusses the free space channel modeling and section 3 illustrates the RoFSO system design. The results are discussed, and the performance of the link is analyzed in section 4 and the section 5 concludes the paper.

Channel Model

The most important environmental agent that affects an atmospheric optical link is fog. This is due to the comparable size of the fog particles and transmission wavelength. Though a shift in the wavelength range is possible, wavelengths beyond the similar range may impose other practical difficulties. The free space attenuation factor α is estimated based on the wavelength of the transmitted light and available visibility as,

$$\alpha = \frac{3.91}{v}\left(\frac{\lambda}{\lambda_0}\right)^q \quad (1)$$

where λ denotes wavelength of transmitted light in nanometers, v points out the available visibility in kilometer units, and q shows the size distribution of the atmospheric particles which causes the scattering which in turn produces the attenuation [7]. A reference wavelength of 550 nanometers used as λ_0 for visibility calculation.

According to the Kruze model adopted in this work for channel modelling, q=1.6 for visibility greater than 50 km, q=1.3 for visibility in the range 50 km to 6 km, and $q=0.58v^{1/3}+0.34$ for visibility less than 6 km. The attenuation factor for different climate conditions can be calculated using (1). The attenuation in decibels τ, can be calculated as [8],

$$\tau = 4.3429 \times \alpha \times L \quad (2)$$

where L is transmission distance. Another important factor that affects the link performance is rain. The attenuation due to rain is given as [3],

$$\alpha_{rain} = 1.076 \times R^{0.67} \left(dB/km\right) \quad (3)$$

where R is the rate of rainfall in mm/h. However, the effect of rain attenuation is comparatively less to that of fog because of the smaller size of optical wavelength compared to raindrops.

The parameters according to Kruze model adopted for various weather conditions are shown in Table 1.

Table 1. Attenuation during various climate conditions for λ=1550 nm using Kruze model [6]

Condition	Visibility [km]	Attenuation [dB/km]
Clear air	23	0.2
Haze	2	2.8
Rain	1	6.5
Light fog	0.8	8.5
Moderate fog	0.6	11.9
Dust fog	0.5	14.7
Dense fog	0.1	90
Heavy dust	0.07	132.8
Heavy fog	0.05	190.9

RoFSO System Design

A 10 Gbps Radio over Free Space Optic system operating at 26 GHz 5G band is proposed and designed here. The simulation setup of the proposed RoFSO system is depicted in Fig. 2. The pseudo random bit sequence (PRBS) generator generates random data at a rate of 10 Gbps. The sequence length set is 1024 bits, and 64 samples are chosen per bit producing a total of 65536 samples. The data is then Non-Return to Zero line coded. The NRZ data is then modulated on the 26 GHz radio frequency signal using an amplitude modulator which produces on-off keying (OOK). For the ease of analysis, advanced modulation schemes are not selected and OOK is used at the baseband modulation level. To grab the various advantages like high data rates and smaller cells, a carrier frequency 26 GHz is selected from the pioneer band of 5G frequencies above 6 GHz [2].

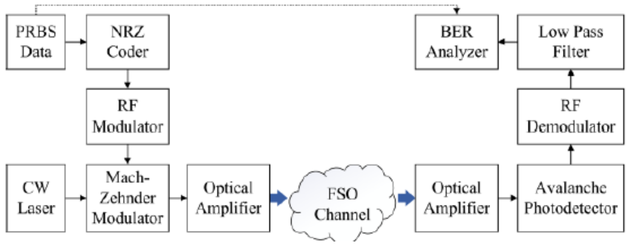

Fig.2. Simulation Setup of the Radio over Free Space Optical Communication Link

A continuous wave laser operating at 1550 nm wavelength and 0 dBm power is selected as the optical source. For efficient modulation and high data rates, external modulation using a Mach-Zehnder modulator (MZM) is adopted instead of direct modulation. The baseband modulated analog RF signal is then modulated on to the 1550 nm light carrier using the MZM. The RF modulated light signal is then amplified using an ideal optical amplifier which provides a gain of 20 dB. Amplifier noise parameters are not considered in this study.

The free space channel attenuation and range parameters are varied for the system performance analysis. The geometrical loss of the link setup is included by selecting transmitter and receiver aperture diameters 10 cm and 45 cm respectively, beam divergence of 2 mrad, and transmitter & receiver losses of 1 dB each. To incorporate the effect of intensity scintillation, two models viz. log-normal [9] and gamma-gamma [10] are available in which the gamma-gamma model is adopted in this work.

At the receiver end, the received optical signals are first amplified using an optical amplifier of 20 dB gain. The amplified signal is then detected, and O/E converted using an avalanche photodiode with a responsivity of 1 A/W. An amplitude demodulator then converts the signals back to baseband and is then purified using a low pass Bessel filter. After filtering, the data is regenerated and is compared with the transmitted data set to evaluate the bit error rate and Q factor performance of the system.

Results & Performance Analysis

To analyze the bit error rate performance, iterations are made on the transmission distance (range) keeping attenuation levels constant assuming different weather conditions. BER performance is calculated for each of the climate condition, setting the attenuation levels from the Kruze model. A combined graph of all the climatic conditions depicting range vs. BER is plotted in Fig. 3 for comparative analysis. From Fig. 3, it can be understood that the proposed RoFSO link performs similar and well for all the climate conditions except dense fog, heavy dust, and heavy fog. These three are the situations where the atmospheric attenuation is greater than 90 dB/km which is very high compared to the other mild weather conditions.

From the Fig. 3, it can also be seen that the link maintains a satisfactory bit error rate of less than 10^{-9} for all conditions other than the above mentioned three. In heavy fog and dust conditions, the link works satisfactorily up to a distance of 300 meters only while it performs well for distances greater than 1 km for all the other weather conditions considered.

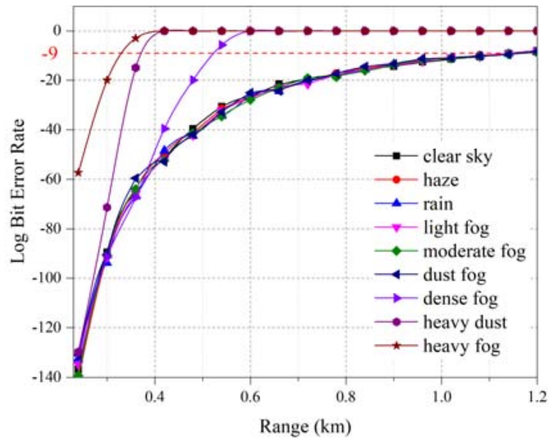

Fig.3. Range vs. Bit Error Rate of the RoFSO Link

Similarly, to analyze the variation in quality factor of the system, the range of the link is varied keeping attenuations constant for each of the weather condition. Range vs. Q Factor performance of the link is plotted in Fig. 4. Akin to the case of BER performance, Q factor performance of all the weather conditions are quite similar except in the dense fog, heavy dust, and heavy fog scenarios. The link maintains a satisfactory Q factor greater than 7 except for the above mentioned three. It is evident from Fig. 4 that, in extreme conditions, the link could maintain the satisfactory Q factor only up to a distance of 300 meters while at other situations it performed well for more than 1 km transmission distance.

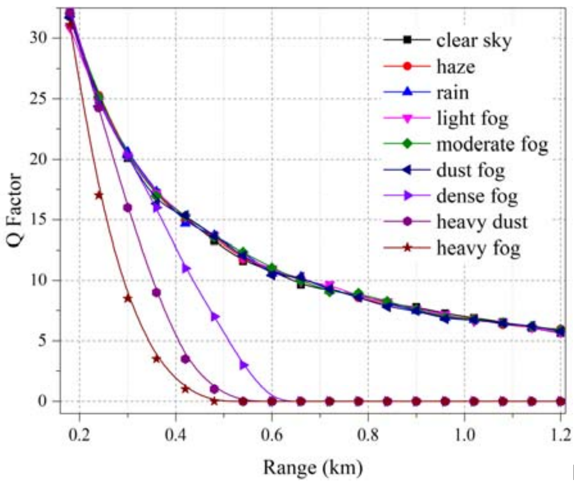

Fig.4. Range vs. Q Factor of the RoFSO Link

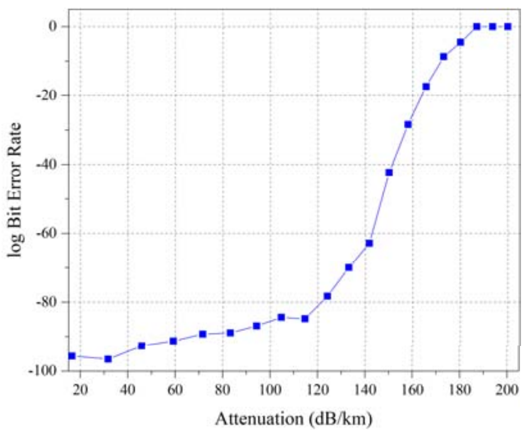

Fig.5. Attenuation vs. Bit Error Rate Performance of the RoFSO Link for a Range of 300 meters

In both the above studies, it is noted that the link performs satisfactorily up to 300 meters in all conditions including the heavy dust and fog scenarios. To investigate further on this, relation between attenuation and BER for a constant link distance of 300 meter is plotted in Fig. 5. From Fig. 5, it can be deduced that the link can provide a satisfactory BER performance of 10^{-9} up to attenuation levels of 170 dB/km under the current system setup.

Conclusion

A quantitative performance analysis of a RoFSO link under adverse weather conditions is carried out using the performance matrices BER and Q Factor. It is found that the proposed RoFSO system for 5G networks is competent to work in almost all the weather conditions except heavy fog and dust. In such scenarios, the link operational range is limited to 300 meters which is still acceptable for most 5G applications. The feasibility of using MIMO links for further range extension in extreme conditions can be considered.

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REFERENCES

[1] A. Gupta and R. K. Jha, A survey of 5G network: architecture and emerging technologies, *IEEE Access*, vol. 3 (2015), pp. 1206-1232

[2] Jan Bohata, Matěj Komanec, Jan Spáčil, Zabih Ghassemlooy, Stanislav Zvánovec, and Radan Slavík, 24–26 GHz radio-over-fiber and free-space optics for fifth-generation systems, *Opt. Lett.,* 43 (2018), 1035-1038

[3] Abhishek Kumar, Prabu Krishnan, Performance analysis of RoFSO links with spatial diversity over combined channel model for 5G in smart city applications, *Optics Communications*, Volume 466 (2020)

[4] H. Kaushal and G. Kaddoum, Optical communication in space: challenges and mitigation techniques, *IEEE Communications Surveys & Tutorials*, vol. 19 (2017), no. 1, pp. 57-96

[5] Dhiman Kakati, Subhash C. Arya, Performance of 120 Gbps single channel coherent DP-16-QAM in terrestrial FSO link under different weather conditions, *Optik*, Volume 178 (2019), Pages 1230-1239

[6] Hosam Abd Elrazek Mohamed Ali, El-Sayed Soliman A. Said, Mohamed Ebrahim Yousef, Effect of environmental parameters on the performance of optical wireless communications, *International Journal of Optics*, vol. 2019 (2019), Article ID 1828275, 12 pages

[7] M. N. Islam and M. N. Al Safa Bhuiyan, Effect of operating wavelengths and different weather conditions on performance of point-to-point free space optical link, *International Journal of Computer Networks & Communications*, vol. 8 (2016), no. 2, pp. 63–75

[8] S. H. Alnajjar, A. A. Noori, and A. A. Moosa, Enhancement of FSO communications links under complex environment, *Photonic Sensors*, vol. 7 (2017), no. 2, pp. 113–122

[9] Fan Bai, Yuwei Su and Takuro Sato, Performance analysis of RoFSO links with diversity reception for transmission of OFDM signals under correlated Log-normal fading channels, *Journal of ICT*, Vol. 2 (2014), 129–150

[10] Wansu Lim, Changho Yun, and Kiseon Kim, BER performance analysis of radio over free-space optical systems considering laser phase noise under Gamma-Gamma turbulence channels, *Opt. Express,* 17 (2009), 4479-4484