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The Analysis of FSO Link Performance in Ulaanbaatar

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Abstract

Recently, developed countries are leading in telecommunications technology, and many studies are being conducted to transmit information through the free space (FSO) or atmosphere using optical frequency light waves. The natural factors that most affect the propagation of optical light waves are fog, rain, and snow. Ulaanbaatar is the capital of Mongolia and has an extreme and variable climate. This paper is devoted to analyzing FSO link performance during data transmission in Ulaanbaatar during heavy rain months (July-August) and simulation using OptiSystem software. Marshall and Palmer's model was used for data transmission using FSO link performance to estimate the rainfall reduction, and several factors such as BER rate and Q factor were investigated. We have made a detailed assessment of the result of rainfall on the FSO system in Mongolia based on the technical data on the weather in Ulaanbaatar in 2018, 2019, and 2020 for the three meteorological station servers of the world weather online site www.worldweatheronline.com.

Keywords: Rainfall, FSO, Q-factor, Rain Attenuation, Marshall-Palmer distribution.

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1. INTRODUCTION

Like optical cables, free-space optical communication (FSO) technology transmits information using light-emitting diodes and lasers. Its main feature is transmitting wireless broadband information by emitting light waves in free space or air [1]. The FSO ground connection includes a horizontal connection network between buildings, from mountain to mountain, or between two stationary stations. FSO system equipment is a low-cost installation technology, operating at temperatures from -50°C to +50°C, making it a suitable technology for Mongolia's harsh climate. The FSO consists of three components: a transmitter that transmits light waves through the atmosphere, a free space transmission channel that is exposed to external influences (clouds, rain, smoke, gas, temperature fluctuations, fog, and aerosols), and a receiver that processes the received signal [2]. Atmospheric absorption is an occurrence that depends on the wavelength. Water, O_2, O_3, and CO_2, which have the highest absorption of infrared wavelengths, reduce the transmission distance. Some values of the molecular absorption coefficients are stated in Table I under clear climate conditions. There are several transmission windows between 700 nm and 1600 nm. Basic FSO systems operate on 850 nm and 1550 nm windows [3].

TABLE I

Absorptions

No	Molecular absorption (dB/km)	Wavelengths (nm)
1.	0.13	550
2.	0.01	690
3.	0.41	850
4.	0.01	1550

Total atmospheric attenuation is defined as the coefficient of atmospheric attenuation, evaluated as a combination of light absorption and scattering [4].

$$\gamma = \alpha_m + \alpha_a + \beta_m + \beta_a \quad (1)$$

Where, α_a and α_m are the air absorption and molecular coefficients, and β_a ба β_m are the air and molecular scattering coefficients [6]. Due to the air molecules' small geometry, the FSO system's transmission attenuation is relatively less.

Random and incalculable environmental factors, such as wind, snow, rain, fog, and haze, can strongly suppress optical signals and limit FSO transmission distance [5]. If parts of the atmosphere are more significant than the wavelength of the optical wave, there will be rain, snow, and hail.

TABLE II

Type of factors

№	Type	Radius (μm)
1	Air molecular	0.0001
2	Haze	0.01-1
3	Fog	1-20
4	Rain	100-10000
5	Snow	1000-5000
6	Hail	5000-50000

The factors shown in Table II contribute to the absorption and distribution in the FSO system. The radius of raindrops (0.1–10 mm) is much larger than the wavelength of conventional FSO systems. The wavelength of light currently used is 1550 nanometers or 1.5 micrometers. Therefore, the raindrops create a geometric scattering and cause attenuation in the FSO system. Therefore, since rain is a more frequent phenomenon than snow, we have selected it and calculated the attenuation [6, 7].

Ulaanbaatar has the highest elevation compared to Mongolia’s central cities, 1350 meters (4429 ft.) above sea level, giving it disparate opposite seasons. To introduce this technology, first of all, it is necessary to calculate the attenuation in Mongolian conditions in detail due to several factors such as rain, snow, fog, and air turbulence that affect the optical light waves. Therefore, the main weather conditions that can cause problems even at short distances are fog and heavy rain. In this research, the impact of rain on FSO communication has been studied using Marshal and Palmer model under Ulaanbaatar city [8]. The rain data is used for the years between 2018 and 2020 for months of rain in July and August and analyzed the extent to which the rain can affect the FSO communication for different transmission power and distance values.

The main problem is that in the case of Ulaanbaatar city, it is impossible to directly measure the speed of rain and the size of raindrops, so it is necessary to use a model for predicting rain extinction. In this study, the Marshall Palmer prediction model proposed by ITU-R is used, and the following measurement values are presented. These values 0.365 for k and 0.63 for a are proposed based on measurements [9]. As for Ulaanbaatar, the amount of precipitation is low because it belongs to a dry climate in the temperate zone. Due to the arid climate, there is very little fog. Most of the previous studies conducted by scientists were conducted in wet or maritime climates of tropical and temperate regions. This study is essential as the first to determine the basic parameters required for introducing this new method of wireless technology transmission of information using optical frequency light waves in Mongolia [10]. The FSO technology uses an atmospheric channel that contains random values of space and time. In the future, it is necessary for Mongolia to research the transmission of information using optical light waves in its atmosphere and weather conditions. We contributed to the first analysis of precipitation reduction in the dry summer of the Mongolian highlands, located in the arid climate of the temperate zone.

The rest of the article is organized as follows. Section 2 describes the estimation of rain attenuation FSO links based on Marshal Palmer distribution. Reviews some models available in the paper to estimate rain attenuation in order to investigate the prediction of rain attenuation on FSO links. The next section of the paper discusses the simulation results obtained from the offered FSO model using OptiSystem. Finally, section 4 concludes the paper.

2. RELATED WORKS

In other to evaluate rain-specific attenuation, novel models are introduced, such as "Carbonneau", "Japan", "Marshall & Palmer", "Prague", and "Malaysia KL". These models are not used for all weather environments due to location-specific features [11, 12]. These models are grounded on k and α coefficients for rainfall rates up to 200 mm/h. But in Ulaanbaatar city, according to the 3-year rainfall study, the maximum amount of precipitation does not exceed 80 mm/hour. Therefore, Carbonneau's model is not appropriate due to low rainfall. The rainfall attenuation found in Marshall Palmer's Ulaanbaatar model is similar to the Japanese model. For the Japanese model, measurements were made at a rain rate of 80-90 mm/h. The researchers noted that using droplet distributions established in other countries could lead to prediction errors when applied to tropical regions [13]. According to the research, it was considered more appropriate to use Marshall Palmer's distribution model in the city of Ulaanbaatar, which has a temperate (arid) region.

3. RAINFALL ATTENUATION

Rainfall models rely heavily on multiple distribution models based on raindrop size. Rain-induced signal attenuation is highly dependent on different patterns of rain distribution. Here, we used the most commonly used rainfall attenuation models, the marshal and palmer rain distribution models. Marshall Palmer's distribution model was selected because it is used in temperate regions like Mongolia and Canada, which have approximate weather. Also, this model was used for the first time in a dry climate. The Marshall-Palmer distributions are based on their own data and the law of Parsons [14].

$$\gamma_{rain} = k \cdot R^{\alpha} \tag{2}$$

Where, R – rainfall speed mm/h, α, and k are model parameters that depend on the size of the raindrops and the temperature at the time of rain. The values of the rain attenuation prediction model for FSO recommended by ITU-R are 1.074 and 0.67, respectively [15].

TABLE III

Rain attenuation prediction model for FSO recommended by ITU-R.

№	Origin	Model	Author	α	k	Region
1	France	Carbonneau	ITU-R	0.67	1.076	Wet
2	Japan	Japan	ITU-R	0.63	1.58	Maritime
3	Switzerland	J.Joss	Bouchet	0.63	0.509	Wet
4	Switzerland	J.Joss	Bouchet	0.63	0.319	Wet
5	Switzerland	J.Joss	Bouchet	0.63	0.163	Wet
6	Canada	Marshall and Palmer	Bouchet	0.63	0.365	Wet
7	Mongolia	Ulaanbaatar (Marshall and Palmer)	Bouchet	0.63	0.365	Arid

Table III shows the ITU-R and other models used for FSO. All of the prediction models are based on temperate weather conditions. Since we have taken frequency of 1550 nm k and α are 0.365, 0.63 respectively, the motive of calculating the attenuation [16].

TABLE IV

Rainfall speed

Year, month	2018, mm/h		2019, mm/h		2020, mm/h	
	7	8	7	8	7	8
Min	1.72	1.55	1.61	1.5	1.85	1.87
Average	18.86	19.25	20.58	19.35	22.55	20.02
Max	61.76	68.53	70.51	60.04	73.7	68.75

Table IV shows the rainfall in Ulaanbaatar in July and August 2018-2020, obtained from "worldweather.com." The rainiest months of July and August in Ulaanbaatar city from 2018 to 2020 have been selected.

TABLE V

Rainfall attenuation

Year	2018, dB/km		2019, dB/km		2020, dB/km	
Month	7	8	7	8	7	8
Min	1.54	1.44	1.47	1.4	1.62	1.63
Average	7.68	7.79	8.14	7.81	8.66	7.99
Max	17.01	18.2	18.59	16.69	19.15	18.3

The extinction was calculated by the Marshall-Palmer distribution, and the results are shown in Table V using the data in Table IV [17]. These models discussed here are based on k and α values for rainfall rates up to 200 mm/h. However, according to a 3-year rainy study in Ulaanbaatar, the maximum rainfall rate does not exceed 80 mm/hour.

4. RAINFALL SIMULATION

We used the OptiSystem software to simulate the basic design of the FSO model. This powerful and flexible tool allows researchers to design, test, and simulate a variety of optical systems. This section describes the simulation analysis and results of the FSO model extracted from OptiSystem tool [20]. The outcomes are surveyed for Ulaanbaatar in Mongolia for the rainy months of July and August by the data of the previous three years, from 2018 to 2020 [Table IV]. To evaluate the execution of the FSO model, we analyze the signal power, Q-factor, and BER at various ranges and transferred optical powers. The wavelength and bit rate used in the analysis was set at 1550 nm and 5 Gbps, 10 Gbps, 20 Gbps, and 40 Gbps. The Q-factor is explored concerning the transmission for various speed values [21].

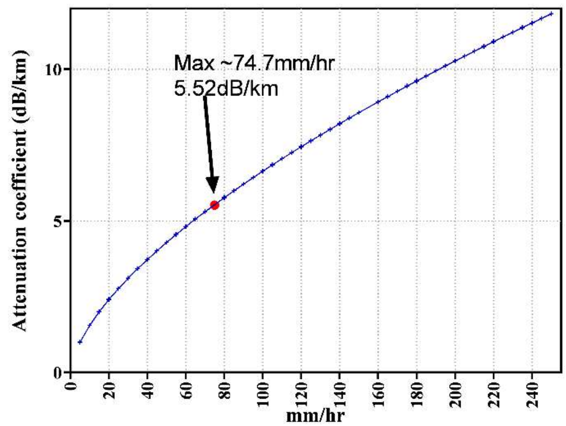

Figure 1. Rain attenuation of rainfall speed

In the case of Ulaanbaatar city, when the maximum rain rate does not exceed 80mm/h, the attenuation value is less than 5.52 dB/km, which shows that transmission is available. Factors influencing the transmission of FSO rainfall in Ulaanbaatar for the last three years have been studied. The increasing rate of rainfall from year to year has led to a decrease in the optical frequency of light waves in the FSO system. In the conditions of Ulaanbaatar city, the attenuation caused by the propagation of optical frequency light waves due to rain in the atmospheric layer was calculated, and the reliable working distance of the optical transmission system was determined and confirmed by the simulation results.

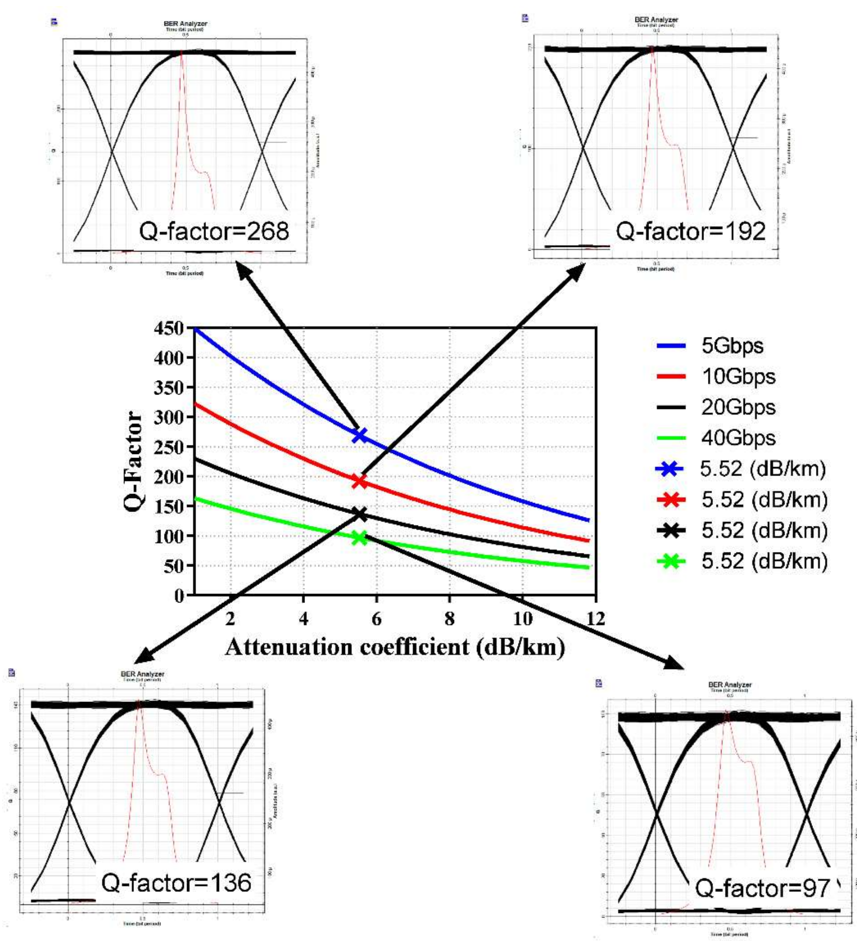

Figure 2. Q factor of 5 Gbps, 10 Gbps, 20 Gbps, 40 Gbps

Figure 2 shows the Q factor and attenuation coefficient variation for different FSO transmission rates. Among the above statistics, the calculation used model is the prediction model proposed by Marshall and Palmer. The frequency of 1550 nm k and α are taken by 0.365 and 0.63, respectively, to calculate the attenuation [25].

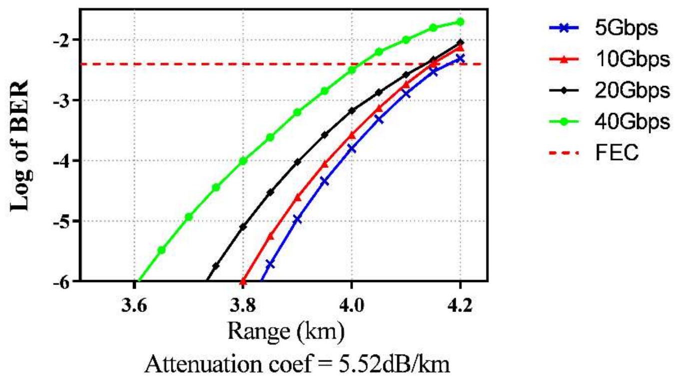

Figure 3. BER performance

BER performance as a function of the FEC (forward error code) with different data rates is shown in Figure 3. It is found that the acceptable distance to obtain the BER value becomes weaker when the data rate becomes higher. In addition, the higher received data rate substantially attenuates the BER. The distance difference between the data rates to obtain the same attenuation coefficient is smaller for the BER result.

5. CONCLUSION

We analyzed the performance of the FSO link rainy months of Ulaanbaatar. The research used rainfall data from July to August 2018-2020 to investigate how rain affects the FSO link for different transmission power and distance values. The FSO system considers the shutdown of Ulaanbaatar during the rainy season, which is the primary atmospheric phenomenon from 2018 to 2020. However, the full use of the FSO system does hamper by problems with the various properties of the atmosphere. From the simulation result, we assume that available propagation distance with data rate of 5 Gbps, 10 Gbps, 20 Gbps and 40 Gbps is at around 4 km in Mongolia. This result suggests that it is possible to increase the transmission distance by reducing the frequency of use. Marshall Palmer's distribution model was considered more appropriate for use in Ulaanbaatar, a temperate region (arid) city. Any preliminary model cannot be a comprehensive model that meets all parameters related to infrastructure installation, geography, and climate change. Most of the predictions of currently developed models are still less accurate, so more effective models for predicting light wave rain attenuation are needed. We believe this study will allow researchers to build a detailed model for predicting rainfall attenuation closer to the regional level.

REFERENCES

[1] Hemani Kaushal and Georges Kaddoum, "Free Space Optical Communication: Challenges and Mitigation Techniques," Department of Electrical, Electronics and Communication Engineering, ITM University, Gurgaon, Haryana, India-122017.

[2] Md Abdus Samad, Feyisa Debo Diba and Dong-You Choi, "A Survey of Rain Attenuation Prediction Models for Terrestrial Links—Current Research Challenges and State-of-the-Art," 2017

[3] Samir A. Al-Gailani, Mohd Fadzli Mohd Salleh, Ali A. Salem, Redhwan Q. Shaddad, Usman Ullah Sheikh, Nasir Ahmed Algeelani, Tarik A. Almohamad, " A Survey of Free Space Optics(FSO) Communication Systems, Links, and Networks," 2017

[4] Hien T. T. Pham, Ngoc T. Dang, Lam T. Vu, and Hieu T. Bui, “A Survey of Performance Improvement Methods for Free-Space Optical Communication Systems,” 2014

[5] Md Abdus Samad, Feyisa Debo Diba, and Dong-You Choi, “A Survey of Rain Fade Models for Earth–Space Telecommunication Links—Taxonomy, Methods, and Comparative Study, “2021

[6] Srikant Patnaik, Srusti Srujanika Sahu, Anshuman Panda, Chandni Jaiswal, ”Free Space Optical Communication: A Review”, 2016

[7] Pawan Singh Vohra, Anuranjana, Sanmukh Kaur, Manpreet Kaur, Aditya Kesarwani, “Analysis of Performance of FSO link during the months of rainfall in Bengaluru, India”, 2018 2nd International Conference on Micro-Electronics and Telecommunication Engineering

[8] Nafaa M.Shebani, Abdalnaser F. Kaeib, Amer R. Zerek, “Estimation of rain attenuation based on ITU-R Model for Terrestrial link in Libya”, Electrical & Electronic Eng. Department, Sabratha University Sabratha, Libya, 2017

[9] J.S.Marshall and W.Mek.Palmer, “The distribution of raindrops with size”, 1948

[10] Abu Jahid, Mohammed H. Alsharif and Trevor J. Hall, “A Contemporary Survey on Free Space Optical Communication: Potential, Technical Challenges, Recent Advances and Research Direction”, 2020

[11] A.Z. Suriza, Islam Md Rafiqul, A.K.Wajdi, A.W. Naji, “Proposed parameters of specific rain attenuation prediction for Free Space Optics link operating in tropical region”, Electrical & Computer Engineering Department, Faculty of Engineering, International Islamic University Malaysia, Malaysia, 2012

[12] AL-Mustansiriyah Univ./College of Science / Physics Department, Iraq – Baghdad, “Analysis Study of Rain Attenuation on Optical Communications Link”, 2014

[13] Yong Chen, Jun-Ling An, Hui-Zhi Liu & Jing Duan, ”An observational study on vertical raindrop size distributions during stratiform rain in a semiarid plateau climate zone”, 2016

[14] Manhal Alhilali, Lam Hong Yin, Jafri Din, “Comparison of Raindrop Size Distribution Characteristics across the Southeast Asia Region”, 2018

[15] Suriza A.Z, Wajdi A.K, Md Rafiqul I, A.W.Naji, ” Preliminary analysis on the effect of rain attenuation on Free Space Optics (FSO) propagation measured in tropical weather condition”, 2011

[16] R.Ghiani, L.Luini, and A.Fanti, ”A physically based rain attenuation model for terrestrial links”, 2017

[17] A.Sree Madhuri, M. Venkata Narayana, Govardhani Immadi, ”Performance Analysis of Single and Multiple Channel FSO System under Turbulent Conditions Using Various Models”, 2018

[18] A.K Rahman, N Julai, C.B.M.Rashidi, Nurdiani Zamhari, S.K Sahari, N.A.A Mohtadzar, M.R.M Sharip,”Impact of rain weather over free space optic communication transmission”, 2019

[19] Umair Ahmed Korai, Lorenzo Luini and Roberto Nebuloni,” Model for the Prediction of Rain Attenuation Affecting Free Space Optical Links”, 2018 December

[20] Abdulrahman A. Yusuf1, Falade, A, Olufeagba, B. J, Mohammed,O.O1, ” Statistical evaluation of measured rain attenuation in tropical climate and comparison with prediction models”, 2016

[21] Ahmed A. Basahel, Islam Md. Rafiqul, A.Z. Suriza and Mohamed H. Habaebi, ”Availability Assessment of Free-Space-Optics Links with Rain Data from Tropical Climates”, 2017

[22] S.Magidi, T. Pondani, “ Estimating the Performance of Free Space Optical Communication in Rain Weather Conditions Using Various Models and Modified Duobinary Return to Zero Technique”, 2020

[23] Gireesh G. Soni, Abhishek Tripathi, Abhilash Mandloi, Shilpi Gupta, ”Effect of wind pressure and modulation schemes on rain interrupted optical wireless links under tropical climates”, 2019

[24] Suriza A.Z., Islam MD. Rafiqul, Wajdi Al-Khateeb and A.W.Naji, ”Analysis of rain effects on terrestrial free space optics based on data measured in tropical climate”, 2011

[25] Report ITU-R F.2106-1, “Fixed service applications using free-space optical links”, 11/2010

[26] Hongwei Xie, Peichong Pan, Haiyun Shi, Ji Chen and Jinzhao Wang, “Observed Microphysical Characteristics of Stratiform and Convective Precipitation over an Inland Arid Region of the Qinghai–Tibet Plateau”, 2020

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