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Development of Opto-Electronic Free Space Optics Rain Attenuation Mathematical Model with Optisystem for Topological Optical link Analysis

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Abstract:

The major obstacle in free space optics FSO is how the data penetrates atmospheric attenuation disturbances like rain, fog, dust storms and snow. The performance of FSO communications is greatly influenced by how one can choose the desired modulation technique. The proposed FSO circuit is designed with a free space range stretching up to 1.85 km. Even though it covers a small radius, we can implement this technique in areas where installing fiber optic cables is impractical. The goal of the proposed work is to use this system to create a new rain attenuation model TSNGH for our region with current rainfall data. For analysis of the FSO circuit under rain attenuation conditions, different kinds of experiments and calculations are carried out with the Optisystem software. With the help of the performance measures; Q factor and BER are evaluated and improved results are accomplished.

Keywords: FSO, Topological Analysis, Rain attenuation models, Modulation technique, BER, Q factor.

1. Introduction

Fiber-optic communication is used to transmit data from one end to another end in the form of light pulses through the optical fiber, whereas the FSO channel is another form of optical communication technique where light is propagated through free space wirelessly to transmit data in telecommunication. Free space refers to mediums like air and a vacuum. FSO and fiber optics are both used to transmit data at a high speed rate. However, the implementation of FSO is easier to install, more scalable and more cost-effective than optical fiber communication. FSO also has a low chance of interception, resulting in higher security and smaller packing. It refers to the transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain broadband communications. FSO mainly operates between 780-1600 nm wavelength bands for electrical to optical and optical to electrical conversions. FSO is mainly used for establishing communication between spacecraft. In our demonstration, we used the Optisystem platform for simulation which helps to simulate various aspects of circuits such as how various digital and analog modulation techniques run and data transmits with different kinds of channels such as optical fiber cables, free-space optical channels, Optical wireless communications OWC and Li-Fi channels. With the help of component properties, the user can easily set the required parameters such as FSO length and varying attenuation values. The attenuation values are based on the condition of rain. Comparison of different communication systems, free space optics can be used for short-range to long-range coverage. There are a lot of applications, challenges as well as limitations in FSO [1], and many methodologies are being developed to mitigate those problems.

2. Related Works

FSO performance can be impacted by various weather conditions. Simulation analyses for different weather conditions are performed at various regions in Lahore, Pakistan using an adaptive FSO/RF link and the results showed that [2], the solution to have good data rate in FSO communication links is at the penalty of increasing the transmitting power in changing weather scenarios. The adaptive system switched to RF when attenuation is high and to FSO link when attenuation is low which reduces the power requirement. The FSO performance is improved under clear and haze conditions using lesser circuitry [3] with the help of one LASER source. A simulation [4] is done using Wavelength-division multiplexing (WDM) FSO and performance is measured for clear and haze conditions while the data rate is set as 10 Gbps. Using an iterative optimization algorithm [5] and enhanced optical communication at a 10 Gbps, the performance was significantly improved for different fog, mist, rain, haze attenuation conditions. Performance analysis of FSO in rainy conditions has been investigated [6] using performance measures like Q factor, received power over a range of 1 km for existing four rain attenuation models. Magidi [7] estimated the performance of FSO with the help of the Modified Duo binary digital modulation scheme wherein the demodulator circuit came across some shortcomings. Performance of FSO is analyzed [8] using the Equal Gain Combining algorithm and differential chaos shift keying, Binary Phase Shift Keying [9] and Co-OFDM under F distribution model of channel [10]. ITU-R rain attenuation models comparison is widely studied [11-14] by researchers across the world for different topological regions. The analytic expressions for finding specific rain attenuation parameters k and α are compared with ITU-R values [15] and the relative errors are observed at any frequency in the Terahertz range [16, 18]. A performance comparison using optical detectors such as Avalanche Photo Diode APD and PIN Photo Diode was done [17]. APD gives the improved Q factor and less BER at the cost of high gain avalanched multiplication, increased biasing and response time. The challenge is obtaining good FSO performance with PIN diode having less gain. This challenge is undertaken in our models and prominent results are obtained. Our objective is on increasing Q factor and reducing BER are achieved for the existing rain attenuation models and the generated new rain attenuation model. We created our circuit using an APD detector but moved to use PIN. Our idea is to create a new predicted rain attenuation model and to analyze the performance of the FSO circuit because there is no rain attenuation model for our region. Calculations based on [11, 15-16] help to create the new rain attenuation model.

3. Proposed Work

To meet increased Q and reduced BER, the FSO layout design is classified into three sections, the transmitter section, medium of transmitter, and the receiver section. The transmitter section involves a user-defined input pseudo random bit sequence generator. Continuous Wave (CW) Laser is used as a carrier to carry the input data in NRZ pulse form with the wavelength of 1550 nm (193.1 THz). The modulation technique used here is On-Off Keying OOK. Mach Zehnder (MZ) modulator is an electro-optical phase modulator that splits light into 2 halves and sends it through different paths. A high-speed electrical signal then changes the phase of the light signal in one path. 2 halves meet at the output and recombine either constructively (bright signal of 1 pulse) or destructively (no light due to signal cancellation so 0 pulse) [19]. The proposed block diagram is given in Fig.1 and the principle of the MZ modulator is represented in Fig 2. The parameter setting in FSO involves fixing a range up to 1.85 km which is almost double the distance of literature works, and attenuation α of rain calculation using the equation

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$$\alpha = K * R^{H}\ db/km \qquad (1)$$

where, R - Rain intensity and K, *H* –power-law parameters

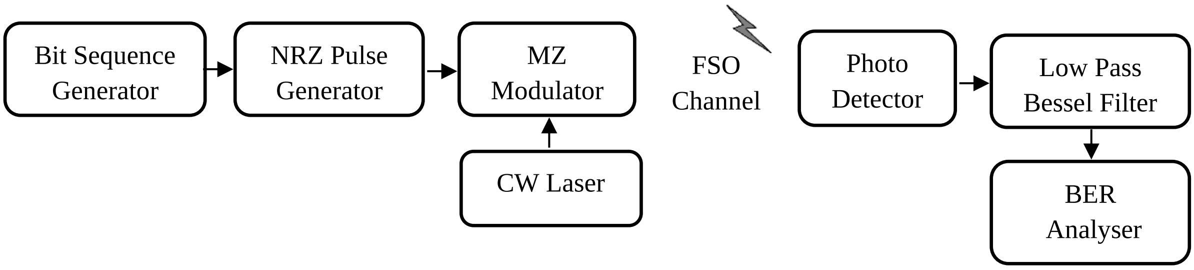

Fig. 1. Block diagram of proposed FSO system

In this method, attenuation due to rain conditions is considered. The modulated data from the FSO channel is passed through the photo detector like PIN or APD which is passed through a low pass Bessel filter with desired cutoff frequency of 0.75*Bit rate HZ to suppresses the noise level in the circuit. The BER analyzer is a visualizer where the performance parameters Q, and BER are analyzed. The layout design and output simulated using the optisystem given in Fig. 3 and Fig. 4.

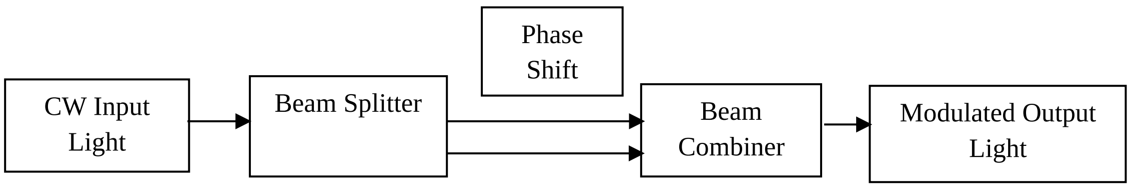

Fig. 2. MZ modulator

The existing rain attenuation models with K, *H* values used in attenuation calculation is listed in Table 1. A model with a high Q Factor and minimum BER values is considered to be the best model. Depending on the comparisons carried out in the experiment across literature papers, Suriza model is considered the best model. We have calculated the attenuation experimentally for all the existing models using Optisystem 7.0, theoretically verified the result, also plotted the graph between Rain Intensity Vs Q Factor and Rain intensity Vs BER.

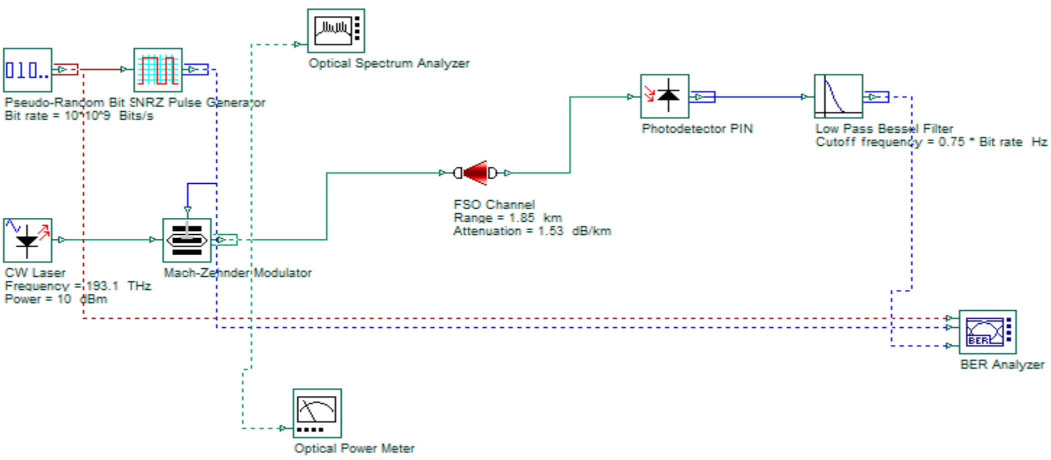

Fig. 3. FSO Transmitter and Receiver layout

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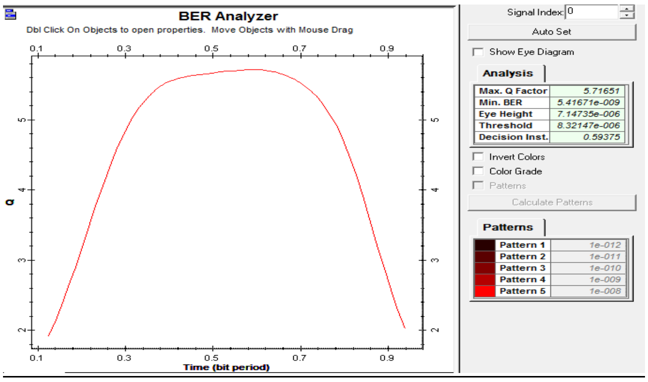

Fig. 4. FSO Output with Performance parameters

TABLE 1. Existing Rain Attenuation Models with model parameters

Model	*K*	*H*
Carbonneau	1.076	0.67
Japan	1.58	0.63
Samir	2.03	0.74
Suriza	0.4195	0.8486

We have experimented with different extinction ratios (the ratio between power in 1 pulse to 0 pulse) as given in equation 2 in MZ Modulator and observed only slight deviations as shown in Fig. 5, Fig.6, TABLE 2. The extinction ratio *Re* is expressed as

$$R_e = P_1 \backslash P_0 \quad (2)$$

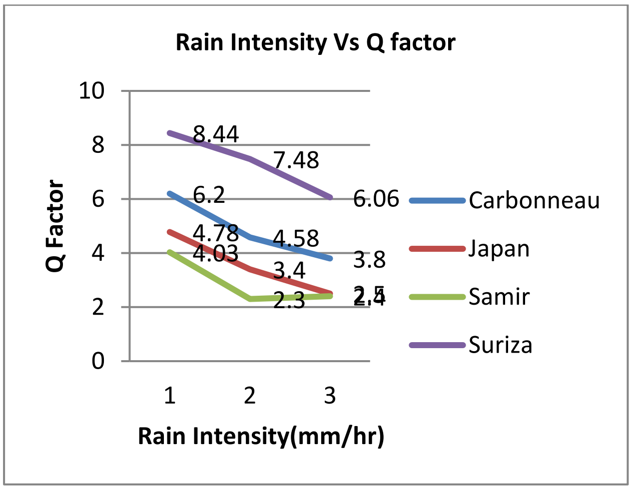

Fig. 5. Q factor for PIN with Extinction Ratio 10 dB

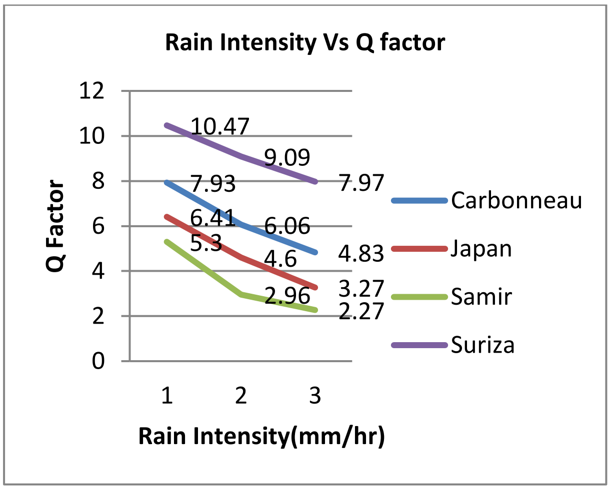

Fig. 6. Q factor for PIN with Extinction Ratio 30 dB

TABLE 2. BER for PIN With Extinction Ratio 10 dB and 30 dB

Rain intensity (mm/hr)	PIN With Extinction Ratio 10 dB				PIN With Extinction Ratio 30 dB			
	Carbonneau	Japan	Samir	Suriza	Carbonneau	Japan	Samir	Suriza
1	10^{-10}	10^{-7}	10^{-5}	10^{-17}	10^{-15}	10^{-11}	10^{-8}	10^{-26}
2	10^{-6}	10^{-4}	10^{-3}	10^{-14}	10^{-10}	10^{-6}	10^{-3}	10^{-20}
3	10^{-5}	10^{-3}	10^{-2}	10^{-10}	10^{-7}	10^{-4}	10^{-2}	10^{-16}

TABLE 3. BER for APD

Rain intensity (mm/hr)	Carbonneau	Japan	Samir	Suriza
1	10^{-103}	10^{-56}	10^{-36}	10^{-91}
2	10^{-41}	10^{-27}	10^{-15}	10^{-80}
3	10^{-31}	10^{-17}	10^{-9}	10^{-62}

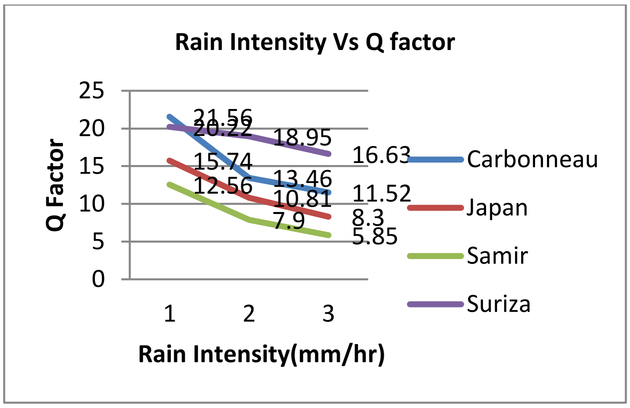

Fig. 7. Q factor for APD

Development of Rain Attenuation Model TSNGH

The new model TSNGH is proposed by analyzing the operating frequency of optical communication is Gigahertz (GHz) range, but Free Space Optical Channel operates only at a frequency of terahertz (THz) which comes under the frequency band of infra-red [20, 21]. With reference to the frequency-attenuation graph [22], it is concluded that when frequency increases attenuation also increases. At higher frequencies attenuation starts to reduce and the attenuation value almost equal to the attenuation at GHz range of frequencies. Attenuation value at 193.1 THz is approximately equal to the frequency of 700 GHz. The new modal is proposed by using the formulae mentioned in the reference [16] and the values of specific attenuation are estimated and the obtained parameters like K_H, H_H, VK, H_V are verified with the ITU Standards, and path elevation θ is deviation from the line of sight which is assumed to 5 degrees and tilt angle T is 45 degree as a rain drop is assumed to be a circular waveguide by which the K, H parameters are obtained for the proposed new model. The sample data used for developing new rain attenuation topological model TSNGH is given in Table 4.

Table 4. September and October month data: Q factor and BER using PIN

District	September month data				October month data			
	Rainfall Intensity (mm/hr)	Attenuation (dB/km)	Q Factor	BER	**Rainfall Intensity (mm/hr)**	Attenuation (dB/km)	Q Factor	BER
Namakkal	1.5	1.92	5.54	10^{-8}	1.71	2.07	5.2	10^{-8}
Virudhunagar	1.74	2.09	5.16	10^{-7}	1.57	1.97	5.43	10^{-8}
Coimbatore	2.54	2.59	4.17	10^{-5}	1.8	2.13	5.07	10^{-7}
Thanjavur	1.25	1.73	6.01	10^{-10}	1.58	1.98	5.41	10^{-8}
Nilgiris	1.5	1.92	5.54	10^{-8}	0.96	1.495	6.65	10^{-11}
Perambalur	3.04	2.87	3.67	10^{-4}	2.23	2.41	4.5	10^{-6}
Tiruvannamalai	2.79	2.73	3.92	10^{-5}	3	2.85	3.73	10^{-5}
Ranipet	2	2.27	4.78	10^{-7}	1.08	1.6	6.36	10^{-10}
Madurai	1.4	1.85	5.71	10^{-9}	1.7	2.06	5.23	10^{-8}
Tirunelveli	1.45	1.89	5.62	10^{-9}	1.65	2.03	5.29	10^{-8}
Chennai	1.71	2.07	5.2	10^{-8}	2.71	2.69	4	10^{-5}

4. Results and Discussion

From the frequency attenuation graph, it is inferred that attenuation is the same for 700GHZ and 193.1THZ. From the recommendation ITU-R (International Telecommunication Union-Recommendation), the specific rain attenuation parameters for 700 GHz is

$K_H = 1.4654\,,\ \ H_H = 0.6284$ (3), $K_V = 1.466,\ \ H_v = 0.6315$ (4)

$$K = (K_H + K_V + (K_H - K_V)cos^2\theta\ cos2T) \quad (5)$$

$$H = (K_H H_H + K_V H_V + (K_H H_H - K_V H_V)cos^2\theta\ cos2T \quad (6)$$

$$\theta = 5\,, T = 45\ degree \qquad Attenuation(\alpha) = K * R^H\ db/km$$

By using this formula, the *K* and *H* values are calculated as *K= 1.53, H=0.566*

According to Indian Meteorological department, meteorology's main monsoons are southwest monsoon and northeast monsoon. The proposed model is based on rain intensities of districts in Tamil Nadu state and the monsoon season taken for estimation mainly depends on North-East Monsoon as Tamil Nadu receives heavy rainfall during the northeast monsoon than the southwest monsoon. The heavy rainfall in Tamil Nadu is mainly during September, October and November. From Table 4, the rain intensity is estimated with the formula of attenuation (dB/km), and this attenuation is included in the FSO channel and the resultant value is analyzed using the BER analyzer which gives the parameters of Q factor, BER. The result shows that when attenuation is high, Q is low and BER is high while attenuation is low, Q factor is high, and BER is low. The BER analyzer parameters are analyzed against Rain intensity (mm/hr) Vs Q Factor and Rain Intensity Vs BER.

Optimized Solution for the Developed Model TSNGH

The main idea of this work is to generate a new rain attenuation model for Tamil Nadu region. Our designed model stands at position 3 compared to other existing models we considered. To further optimize the model, we focus on the following calculations.

$$K_H = \{(3.8794.10^{-5} f)^{(2.7474 - 1.7941\ln(f) + 1.1805 ln^2(f) - 0.202 ln^3(f)} \quad for\ 1 \le f \le 20GHZ\ \}$$

$$\{(8.2522 * f^2 * 10^{-5} / (1 - 0.1950\, ln(f) + 6.2033 * 10^{-5} f^2 \quad for\ 20 \le f \le \quad 400GHZ\}$$

(7)

$$H_H = \{\frac{(1.0564\ln(f) - 1.9256)^2 + 0.9437}{(1.1141\ln(f) - 2.0940)^2 + 0.7181}\ \} \qquad for\ 1 \le f \le 20GHZ$$

$$\{0.6828 + \frac{0.5018}{(1 + 2.0946 * 10^{-4} f^{(2.2862)}\}} \qquad for\ \ 20 \le f \le 400GHZ$$

(8)

$$Kv = \{(3.5807 * 10^{-5} f^{(2.6034 - 1.617\ln(f) + 1.0940 ln^2(f) - 0.1877 ln^3(f)} \qquad for\ 1 \le f \le 20GHZ$$

$$\{((7.9130 * 10^{-5} f^2)/(1 - 0.1865\ln(f)) + 5.9357 * 10^{-5} f^2 \qquad for\ 20 \le f \le 400GHZ \quad (9)$$

$$H_V = \{((1.0246\ln(f)) - 1.9462)^2 + (0.9048))/((1.1073(\ln(f)) - 2.1584)^2 + (0.6972)) \qquad for 1 \le f \le 20GHZ$$

$$\{(0.6833 + (\frac{0.4494}{1 + 1.8700 * 10^{-4} (f)^{(2.2862)}}) \qquad for\ 20 \le f \le 400GHZ$$

(10)

After frequency mapping,

$$K = (K_H + K_V + (K_H - K_V)cos^2\theta\ cos2T) \quad (11)$$

$$H = (K_H H_H + K_V H_V + (K_H H_H - K_V H_V)cos^2\theta\ cos2T \quad (12)$$

$\theta = 5,\ T = 45\ degree$ $\qquad$ $Attenuation(\alpha) = K * R^H\ db/km$

$K_H = 0.7471573,\ K_V = 0.772433874,\ H_H = 0.393040512,\ H_V = 0.393346273,\ K = 0.1957\ H = 0.367$

TABLE 5. BER comparison between the existing four models (Carbonneau, Japan, Suriza, Samir) and the new model (TSNGH) Before and After frequency mapping

Rain intensity (mm/hr)	Before frequency mapping					After frequency mapping				
	Carbonneau	Japan	Samir	Suriza	TSNGH	Carbonneau	Japan	Samir	Suriza	TSNGH
1	10^{-15}	10^{-11}	10^{-8}	10^{-26}	10^{-11}	10^{-19}	10^{-16}	10^{-13}	10^{-25}	10^{-27}
2	10^{-10}	10^{-6}	10^{-3}	10^{-20}	10^{-7}	10^{-15}	10^{-11}	10^{-8}	10^{-21}	10^{-26}
3	10^{-7}	10^{-4}	10^{-2}	10^{-16}	10^{-5}	10^{-13}	10^{-9}	10^{-6}	10^{-19}	10^{-25}

From Fig. 8, Fig. 9 and Table 5, we can conclude that the new rain attenuation model TSNGH gives a better Q factor and min BER compared to other existing models. This is achieved by equalizing the frequency to 400 GHz from 700 GHz. When we have a better Q factor and min BER, we can say the system is a good performance system. After optimizing the solution our model satisfies these criteria. So, we concluded that our model achieved a good performance.

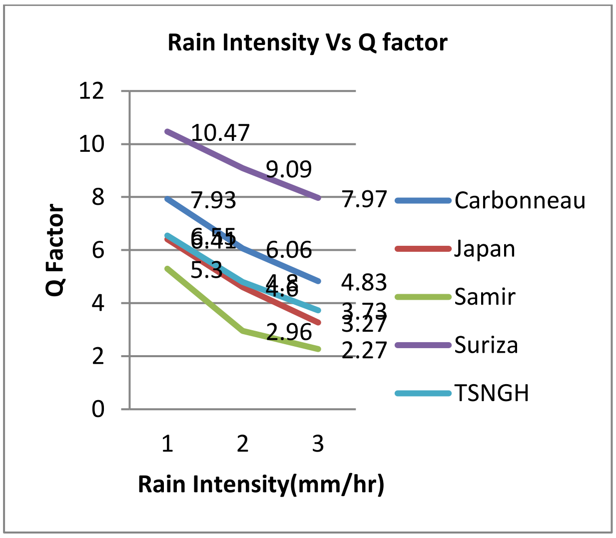

Fig. 8. Comparison of Q factors for different models after frequency mapping without optimization.

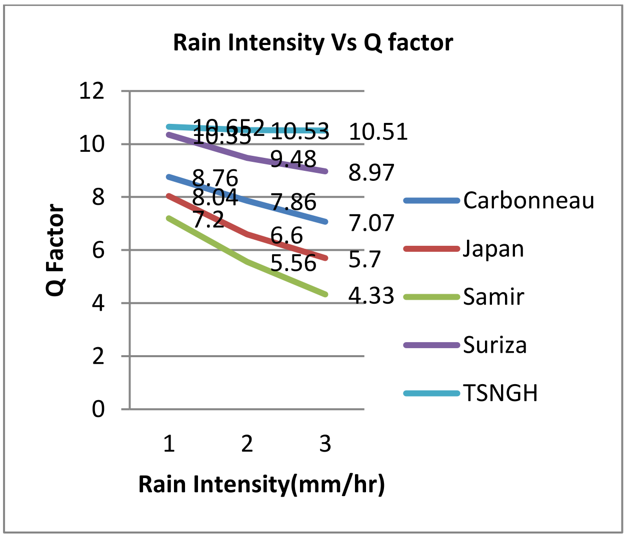

Fig. 9. Comparison of Q factors for different models with optimized model after frequency mapping.

Conclusion

In this article, we have experimentally studied attenuation of rain through the FSO channel where attenuation of different models like Carbonneau, Japan, Samir, and Suriza was analyzed with the performance parameters Q factor and BER. A comparison of the existing models is carried out with APD and PIN detector. A new model is created with the help of ITU-R by frequency mapping from the Frequency-attenuation graph. The real-time rain data for various districts in Tamil Nadu is collected and rain attenuation is calculated. From this, we inferred that when attenuation is high, Q factor is low and BER is high and the reverse is also true. By this inference, while the frequency range is restricted an optimized result is generated with a high Q and low BER value. By claiming the performance status of high Q and low BER the new rain attenuation model (TSNGH) is proclaimed as the Best Model among the existing model. We hope that our TSNGH model will serve as the base for future research in free-space optics to develop a new model for their topological regions.

References

[1] Aditi Malik and Preeti Singh, Free Space Optics: Current Applications and Future Challenges, Hindawi Publishing Corporation International Journal of Optics Volume 2015, Article ID 945483.

[2] Sultan Mahmood Yasir, Naeem Abas, Areeba Rahman, Muhammad Shoaib Saleem, Simulation analysis of adaptive FSO/RF hybrid link under diverse weather conditions of Lahore, Pakistan 2021 Results in Optics ELSEVIER.

[3] Aditi Malik ·Preeti Singh, Comparative Analysis of Point-to-Point FSO System Under Clear and Haze Weather Conditions, 2014 © Springer Science + Business Media New York

[4] Mohammad Yawar Wani, Hitesh Pathak, Karamjit Kaur, and Anil Kumar, Free space Optical Communication System under different weather conditions, April 12, 2019 De Gruyter Journal of Optical Communication.

[5] Gebrehiwet Gebrekrstos Lema, Free space optical communication system design using iterative optimization, 2020 De Gruyter Journal of optical Communication.

[6] GovardhaniImmadi M. Venkata Narayana Sarat K. Kotamraju A. Sree Madhuri, Estimating the Performance of Free Space Optical Link Under Adverse Weather Conditions by Using Various Models, 2018 Springer Science + Business Media, LLC, part of Springer Nature.

[7] S. MagidiT. Pondani, Estimating the Performance of Free Space Optical Communication in Rain Weather Conditions Using Various Models and Modified Duobinary Return to Zero Techniques, 2020 The National Academy of Sciences - Springer- Scientific Research Paper.

[8] G. Narang, M. Aggarwal, H. Kaushal, A. Kumar and S. Ahuja, "Performance Analysis of Differential Chaos Shift Keying in Free Space Optical Communication With Diversity Techniques," in IEEE Access, vol. 11, pp. 54438-54447, 2023, doi: 10.1109/ACCESS.2023.3280055.

[9] Chauhan, S, Miglani, R, Kansal, L, Gaba, G.S, Masud, M, Performance Analysis and Enhancement of Free Space Optical Links for Developing State-of-the-Art Smart City Framework. Photonics 2020, 7, 132. https://doi.org/10.3390/photonics7040132.

[10] Bipin K. Saw, Vijay Janyani, Ghanshyam Singh, Analysis of coherent-OFDM modulation for FSO communication over distribution with pointing errors, Optics Communications, Volume 545, 2023, 129677,
ISSN 0030-4018, https://doi.org/10.1016/j.optcom.2023.129677.

[11] AhmedBasahel, Islam Md.Rafiqul, Mohamad Hadi Habaebi and A. Z. Suriza, A proposed rain attenuation prediction method for free space optical link based on rain rate statistics, Vol. 10, No. 23, December 2015 ISSN 1819-6608 ARPN Journal of Engineering and Applied Sciences.

[12] 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, IIUM Engineering Journal, Vol. 12, No. 5, 2011: Special Issue -1 on Science and Ethics in Engineering.

[13] Samir A. Al-Gailani, Abu Bakar Mohammad, Usman U. Sheikh, Redhwan Q. Shaddad,

Determination of rain attenuation parameters for free space optical link in tropical rain, Optik, Volume 125, Issue 4, 2014, pp. 1575-1578, ISSN 0030-4026, https://doi.org/10.1016/j.ijleo.2013.10.018.

[14] P.J. Gripeos, H.E. Nistazakis, K. Aidinis, D. Kriempardis, G.S. Tombras, Performance investigation of FSO communication systems with chromatic dispersion, propagation losses and truncated normal modeled time jitter, Optics Communications, Volume 532, 2023, 129218, ISSN 0030-4018, https://doi.org/10.1016/j.optcom.2022.129218.

[15] Zhen-wei Zhao, Ming-gao Zhang, and Zhen-sen Wu, Analytic Specific rain attenuation model for rain for used in prediction methods, 2001, International Journal of Millimeter and Infrared waves, Volume 22, No 1.

[16] Rec. ITU-R P.838-3 1Recommendation ITU-R P.838-3 Specific attenuation model for rain for use in prediction methods, P.838 : Specific attenuation model for rain for use in prediction methods (itu.int)

[17] Priyanka Sharma and Himali Sarangal, Performance Comparison of APD and PIN Photodiodes using Different Modulation and Different Wavelengths, International Journal of Signal Processing, Image Processing and Pattern Recognition, Volume 9, No.4 (2016), pp.257-264

[18] G. Stephen Mecherle, Mitigation of atmospheric effects on terrestrial free-space optical communication systems, Free-Space Laser communication Technologies XVI SPIE, Volume 5338, 2004.

[19] Noelia Matinez, Luis Fernando Rodriguez Ramos, Zoran Sonik, Simulating the performance of adaptive optics techniques on FSO communications through the atmosphere, Laser Communication and Propagation through the Atmosphere and Oceans VI SPIE Optical Engineering + Applications, Volume 10408, 2017.

[20] Chengsheng Pan, Xin Shi, Chengyang Liu, Xue Wang, Yuanming Ding, Simulation and analysis of atmospheric transmission performance in airborne Terahertz communication, Novel Optoelectronic Detection Technology and Application SPIE Volume 10697, 2018.

[21] Liao, X.; Fan, L.; Wang, Y.;Yu, Z.; Wang, G.; Li, X.; Zhang, J.Attenuation Characterization of Terahertz Waves in Foggy and Rainy Conditions at 0.1–1 THz Frequencies. Electronics 2023, 12, 1684. https://doi.org/10.3390/electronics12071684

[22] J. F. FEDERICI, New Jersey Institute of Technology, USA,L. MOELLER , Bell Laboratories, Alcatel-Lucent, USA and K. SU , New Jersey Institute of Technology, USA-Terahertz wireless communication Page no 163.

[23] Rajput, B. S. .; Gangele, A. .; Alaria, S. K. . Numerical Simulation and Assessment of Meta Heuristic Optimization Based Multi Objective Dynamic Job Shop Scheduling System. *ijfrcsce* 2022, *8*, 92-98.

[24] Satish Kumar Alaria, Manish Kumar Mukhija, and Pooja Singh "A Security Approach to Manage a Smart City's Image Data on Cloud," AI-Centric Smart City Ecosystems: Technologies, Design and Implementation (1st ed.), PP: 68-82, (2022). CRC Press. https://doi.org/10.1201/9781003252542.

[25] S. K. A., A.. Raj, V. Sharma, and V. Kumar.“Simulation and Analysis of Hand Gesture Recognition for Indian Sign Language Using CNN”." *International Journal on Recent and Innovation Trends in Computing and Communication* 10, no. 4 (2022): 10-14.

[26] On abstract Cauchy problems in the frame of a generalized Caputo type derivative. (2023). Advances in the Theory of Nonlinear Analysis and Its Application, 7(1), 01-28.