



Prediction of Free Space Optical Link Availability using Visibility Variations of Selected Meteorological Parameters in Kaduna State: A Technical Literature Review

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ABSTRACT

Free Space Optical Communication (FSOC) is a communication system where free space acts as a medium between transceivers which are in a line of sight (LOS). The transmission in FSO is dependent on the presence of meteorological parameters such as rain, fog, haze, mist, physical obstruction, atmospheric turbulence etc present in the atmosphere. With recent advances and interest in Free Space Optics (FSO) for commercial deployments, a proper understanding of optical signal propagation in different atmospheric conditions has become essential, and thus arise the need to rationalize the effects of atmospheric channels on terrestrial FSO link availability. In this paper, we survey prediction methods required for the design of free space optical links based on measurement data which are unique for a particular geographical location.

ARTICLE INFO

Article History

Received: March, 2022

Received in revised form: April, 2022

Accepted: May, 2022

Published online: June, 2022

KEYWORDS

Free Space, Optical Link, Meteorological Parameters, Kaduna State.

INTRODUCTION

Free space optics (FSO), also known as fiber-free or fibreless photonics, refers to the transmission of modulated light pulses through free space (air or the atmosphere) to obtain broadband communications. Laser beams are generally used, although non-lasing sources such as light-emitting diodes (LEDs) will serve the same purpose. FSO can be the best wireless solution where fibre optical cable is not available, high bandwidth (anywhere from 100 Mbps up to 2.5Gbps) is required, and line-of-sight can be obtained to a target within a couple of miles. (Sadiku *et al.*, (2016).

In terms of broadband communication service, FSO is regarded as a suitable candidate to offer this service to the end users, with a specific demand for point-to-point connection, under a clear atmospheric environment between transmitter and receiver. In comparison to fibre optic transmission, the FSO technologies are principally the same. The difference is that FSO output is collimated and transmitted through the atmosphere, while fibre optic transmission will have its output transmitted via optical fibre. FSO provides a unique alternative

compared to the current technologies, which can meet the exponentially growing demand for bandwidth. Most importantly, optical fibre cable can be replaced with FSO systems in scenarios where either cable cannot be laid or requires high capital expenditure (Al-Gailani *et al.*, 2021). Some of the key advantages of FSO technology are large bandwidth, immunity to electromagnetic interference, no spectrum licensing, and higher data rate. However, an FSO transmission is prone to non-ideal conditions arising from unstable weather conditions. In another word, a single beam FSO system is susceptible to weather conditions whereby turbulence, rain, fog, haze and dust introduces attenuation to the light source or even block the propagation. Hence, the FSO system should be thoroughly investigated relative to weather conditions, to ensure that the received power is sufficient at the receiver for processing. Many studies were carried out under different environmental conditions and their relative impact on the performance of the FSO system (Al-Gailani *et al.*, 2021).

The disadvantage of FSO over fibre is that laser power attenuation through the atmosphere is variable and difficult to predict since



it is weather dependent, on the link availability as a function of distance can be predicted for any FSO system (Kaur & Amandeep 2017). These availability curves provide a good indication of the reasonable link distances for FSO systems in a particular geographical area. The carriers and ISPs are another potential large user of FSO systems, especially for last-mile metro access applications. If FSO systems are to be used in telecommunication applications, they will need to meet much higher availability requirements. Carrier-class availability is generally considered to be 99.999%. An analysis of link margin analysis and visibility-limiting weather conditions indicates that to meet carrier-class availability ((Kaur & Amandeep 2017).

REVIEW OF SIMILAR WORKS

Aremu *et al.*, (2015) examined the characterization of signal loss due to dense fog of optical wireless communication systems in Ibadan, Southwestern Nigeria. their work shows that in dense Fog condition when the visibility is less than 500m, the attenuation of the signal takes the same value for both 850nm and 1550nm window. Therefore, the atmospheric attenuation is independent of the wavelength. But it decreases as the visibility increases. Their result revealed that 850nm and 1550nm attenuated the same when visibility is less than 500m. The result also shows that no wavelength dependency was found for visibilities below a few hundred meters for the investigated wavelengths between 850nm and 1550nm window, indicating that the Kim equation fits better to measurement data. However, the drawback to this research was that only dense fog was considered which was not enough to account for the atmospheric effect on FSO link performance and also performance metrics were not considered.

Kora *et al.*, (2015) investigated the Free Space Optics attenuation Model for Visibility ranging from 9 – 12km. Based on their collected field data, their research shows the limitations of existing attenuation models precisely for visibility ranging from 9 Km to 12 Km. A more explicit and accurate expression of the parameter “q” previously considered as a constant in Kruse empirical attenuation formulas for different visibility intervals has been derived to fill the gap

between theory and experience. The comparison of their proposed Kruse rewritten model based on field data has shown the accuracy of the reformulated attenuation model. However, the limitation to their research was that they only consider visibility range from 9 – 12km and the daily changing atmospheric conditions which severely degrade the FSO link and significantly affect the daily visibility was also not considered.

Mushtaq *et al.*, (2017) researched the attenuation of free space optical communication under the dusty conditions in Lahore of Pakistan. In their research work, a Simulation of FSO communication using MATLAB was conducted, and the laser beam propagates through the atmosphere in the form of EM waves. The suspended particles in the air degrade their performance. The suspended elemental particles of high concentration reduce the visibility of the signal and enhance the attenuation of the signal. The above results may be quite similar for the areas having the same meteorological conditions as Lahore. The atmospheric conditions are location-dependent and may vary from one place to another. However, the limitation of their research was that only dust concentration was considered but other major weather conditions that play a significant roles in degrading FSO link performance are not considered such as fog, haze, rainfall rate etc.

Mushtaq *et al* (2018) carried out an analysis of internal design parameters to minimize geometrical losses in free space optical communication links. In the research work, the analyzed different parameters of system design to minimize the geometrical losses. They presented the analysis of internal design parameters like divergence angle, the diameter of receiver aperture, the diameter of transmitter aperture, and link distance and suggested the suitable parameters of system design. However, the performance of the FSO link depends upon both the atmospheric conditions and the internal design parameters in the internal design parameters depend on the unpredicted parameters which are the meteorological parameters.

Anis *et al.*, (2018) evaluate the FSO system availability in Haze Conditions. The researchers proposed the evaluation of FSO system availability in haze conditions. The



atmospheric attenuation by weather conditions in the atmosphere is the most challenging problem for the FSO system as the system performance was severely degraded and caused the signal optic to be transmitted poorly. The effects of haze condition on the performance of the FSO system was stressed out and focused on in this research work. From the evaluation of the analysis, designs of the Subsystem were proposed to obtain a system with improved link performance in haze conditions. The scattering coefficient and the atmospheric attenuation were determined using Beer's Lambert equation. From the research, the link performance of the system was greatly improved using Design2 with a minimum BER of 10^{-127} and a maximum Q Factor of 23.98. The FSO system using Design2 has a better performance compared to Design 1 in haze conditions as the optical signals could penetrate the dense haze better without losing much optical power during the transmission. However, the major drawback of the work was that, only Haze was considered while other important weather conditions not considered are Fog and Rain rate which severely affect the communication link. Also, the performance indicators considered were not enough for the work. Falodun *et al.*, (2019) analyzed visibility effects on free space Earth-to-Space Satellite Optical Link based on measurement data in Nigeria.

They analyzed the effect of fog on FSO communication links from earth to satellite links over five selected locations (Ikeja, Akure, Enugu, Jos and Port-Harcourt) in Nigeria. One year (2012) visibility data was obtained at Nigeria Meteorological Agency (NIMET) which was used to estimate the specific attenuation caused by fog on FSO communication links in the selected locations. Link margin was deduced in all five locations. The estimated specific attenuation caused by fog was based on operating frequencies associated with a typical commercial FSO. Their result shows that Ikeja recorded the highest value of about 38.60 dB/km for the specific attenuation due to fog on the FSO link followed by Akure with a value of about 30.33 dB/km. Enugu recorded the least estimated attenuation of about 14.19 dB/km. Their result implies that Ikeja and Akure will suffer more signal loss, while Enugu will suffer less signal loss. The result on link margin

performance on the FSO link also showed that Ikeja has the highest link margin of -109.79 dB, Port-Harcourt with a link margin value of -91.99 dB while Jos experienced the lowest link margin of about -37.48dB. However, the drawback to their research was that only fog-induced attenuation was considered and link margin as performance metrics which were not enough to achieve optimum performance of FSO links. Other meteorological parameters should be considered such as Rain rate, haze and also received power and data rate should be considered as performance metrics.

Ajewole *et al.*, (2019) investigated fog and rain-induced specific attenuations for terrestrial FSO communication in Akure, Ondo State, Nigeria. Retrieved one year archived visibility and rain data have been used to compute both fog and rain-induced attenuation losses at five optical wavelengths of 650, 750, 850, 950 and 1550 nm, at 2% transmittance thresholds. Results on the fog-induced specific attenuation show peak values of about 122.14, 109.96 and 86.91 dB/km at 650, 850 and 1550 nm wavelengths respectively. Their result shows that fog-induced specific attenuation generally decreases with increasing optical wavelength. Results on the link margin analysis considering geometric and fog-induced losses show that the proposed FSO system with a commercial optical transceiver, Telescope 5000 gives an acceptable performance at a 2 km link distance at all the wavelengths considered. At a farther link distance of 5 km, the link will only perform suitably at higher wavelengths of 950 and 1550 nm. However, the limitation to this work was that haze was not considered in the research work being one of the major contributing factors to signal to scatter in FSO link and also the one-year period considered was not enough.

Farouk & Ali (2019) researched free space optical communication links under Foggy conditions. FSO systems offer a viable solution for building visual communication in a cost-effective, performance fast and reliable manner in certain situations. Different weather conditions such as fog effects will affect the work of FSO communications systems. In their work, they discussed the impact of fog weather as considered the important parameter affecting the



performance of the FSO system. The received signal power and signal-to-noise ratio were performed in fog weather conditions. The results showed that BER increased by increasing the divergence angle and the strength of the received signal increased significantly with the increase of the receiver diameter for the parameters under study. It was noted that haze and light fog had a preference performance and that the signal was of good quality compared to heavy fog. However, other atmospheric conditions such as haze and rainfall rates that significantly hinder the free space optical link were not considered.

Ahmed *et al.*, (2020) investigated the effects of atmospheric conditions on the quality of free space optical communication links in Nigeria using Bauchi as a case study. In their work, the average wind speed (m/s) and the altitude (m) of Bauchi were considered. These values were used to calculate the refractive index structure parameter for all the locations. Bauchi has a refractive index structure parameter of 1.2431×10^{-16} at an altitude of 621m. These results indicate that altitude has a significant impact on the refractive index structure parameter. As the altitude increases the refractive index structure parameter decreases. An optimal link distance is achieved when the power link margin is equal to or greater than the total atmospheric loss. Bauchi has link distances ranging from 6300 to 6600m with similar atmospheric losses. It can be concluded that at average atmospheric conditions FSOC can be deployed. At worst atmospheric conditions, scattering loss increases due to lower visibilities. Bauchi has a low total atmospheric loss, resulting in the longest FSOC link at 4535m which satisfies the minimum visibility requirement of FSOC. Under worst atmospheric conditions, therefore, FSOC can be deployed in these locations. However, the limitation of this research work was that major meteorological parameters that severely degrade the performance of FSO were not considered only wind speed and altitude were considered.

APPLICATIONS

The Number of Potential Applications in Various Fields of FOS Communication System Has Been Observed as Mentioned below (Farooq *et al* 2020):

- i. **Military Access:** FSO has got the advantage of being secure and undetectable as it uses narrow beam width for data transmission. Hence, it can provide a secure connection in large areas with minimal planning and less deployment time, which makes it most suitable for military access
- ii. **Point-to-Point and Point-to-Multipoint Communication:** FSO communication is possible in point-to-point links, for example, between two shops, or two buildings, and also in point-to-multipoint links, for example, from satellite to ground for short as well as long-distance communication
- iii. **Last Mile Access:** The last mile has always been a bottleneck for most of the telecommunication, cable television, and Internet industries. FSO can provide a solution to this problem by deploying it at the last mile along with other networks.
- iv. **Storage Area Network (SAN):** SAN is a network that provides access to consolidated block-level data storage. FSO links can be used to form a SAN and also on campuses, FSO is providing fast Ethernet or gigabit Ethernet speeds for LAN-to-LAN connections. In metropolitan area networks, FSO provides LAN-to-LAN connections. For certain specific events or purposes, FSO provides temporary networks such as disaster recovery, and FSO provides re-establishment of high-speed connections quickly. FSO may be used to upgrade existing wireless technologies. FSO provides an effective backup for important fibre connections.

CONCLUSION

In this paper, a brief literature review on the challenges, application and performance of free space optical communication links is discussed. The paper demonstrates availability prediction methods for FSO links. The methods are developed based on measured meteorological visibility data of local weather conditions which can be modelled based on empirical mathematical



models and the measured visibility data that is unique to a particular geographical location around the globe. Also, FSO link availability can be predicted by calculating the link margin analysis of an FSO communication link.

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