

# Design and Performance Evaluation of Free Space Optical Communication Link in Zaria, Nigeria

A.S. Bukar\*, H.A. Adamu, H.A. Abdulkareem, H. Bello, M.D. Almustapha, E.E. Agbon  
Department of Electronics and Telecommunication Engineering Ahmadu Bello University, Zaria  
[asamailabukar@gmail.com](mailto:asamailabukar@gmail.com)\*

\*Corresponding Author

## Abstract

*Free Space Optical Communication (FSOC) is an optical technology with a great chance to complement traditional wireless communication technologies. It offers essential advantages compared to Radio Frequency (RF), such as low power consumption, no frequency restrictions, no electromagnetic interference, security, and a significant increase in bandwidth. Similarly, they have proven a worthy substitute for fiber optics with notable advantages. FSOC systems are usually installed above ground level and are therefore exposed to prevailing weather conditions such as haze, fog, rain, etc. which negatively affect the optical signal transmission. There is a shortage of research on using FSO systems in tropical regions. For this reason, accurate free space optical communication channel modeling helps telecommunication operators to engineer and appropriately manage their networks. Therefore, this research work developed Free Space Optical Communication Channel Model to mitigate the effects of atmospheric attenuations by estimating the specifically induced attenuation caused by both haze and rainfall rates on the FSOC link in the Zaria geographical area using two years of measured visibility data and rainfall rates data of the study location obtained from Nigerian Meteorological (NIMET) agency, Zaria station, located at the Nigeria College of Aviation Technology (NCAT) Zaria and Center for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria. The performance of the FSOC system is analyzed and evaluated through Link Margin (LM) analysis by using the design specifications of a commercial optical transceiver (TereScope 5000). The haze-induced attenuation obtained at 850nm, 950nm, and 1550nm is 5.934dB, 6.402dB, and 3.152dB respectively. Therefore, the result shows that the 1550 nm wavelength has minimum haze-induced attenuation compared to 850nm and 950nm at a propagation link distance of 6km. Furthermore, from the results of the performance evaluation of the LM analysis for the combined effects of Geometrical Attenuation ( $G_{att}$ ), Haze-Induced Attenuation (HIA), and Rain- Induced Attenuation (RIA), the result shows that operating a 1550nm wavelength in transmission power greatly improves optical transmission when compared with 850nm and 950nm wavelengths. Generally, the overall outcome of the research concludes that the free space optical communication system has the robustness to handle successful wireless communication during the worst weather conditions in Zaria throughout the year for a link range of up to 6km.*

**Keywords:** FSOC, Visibility, Haze, Rainfall rates, Link Margin, Optical Attenuation

## 1. Introduction

Current wireless communication technologies have displaced the radio and microwave frequency bands that have become excessively overcrowded. Free space optics (FSO) has enormous bandwidth making it a fascinating solution for bandwidth consumption. FSO is similar to fiber technology. However, in FSO, data is transmitted in the air, whereas in fiber, it is enclosed in glass. FSO technology does not require licensing for installation. The FSO technology addresses many applications, like communication between buildings, backhaul wireless communication systems, indoor links, fiber communications backup, satellite communications, etc. (Esmail et al., 2016). Despite all the advantages and the variety of FSO applications, the FSO link is seriously affected by the presence of hydrometeors in the atmosphere. These include moisture, rain, snow, haze, mist, etc. Among the hydrometeors, fog is the most deleterious to an FSO system (Ajewole et al., 2019). Studies have shown that attenuation in the FSO system has a peak attenuation value of 480 dB/km under dense fog (Esmail et al., 2016).

This paper presents the impairments caused by haze and rainfall rate on an FSO link system in Zaria and its environs. Furthermore, we studied the performance of the FSO system under the prevailing weather conditions of the study area using link margin analysis as the performance metric. Several kinds of research have been carried out across Nigeria, but to the best of our knowledge, there was no empirically based study of FSO link availability completed in the study area previously. Therefore, this research describes the development of the FSOC channel mathematical model for Zaria and its environs to predict haze and rain attenuations on FSO links for a path length of up to 6km which will serve as a reference for future link establishments in the study area. The rest of the paper is organized as follows. Section two reviews relevant works carried out and published by other researchers and theoretical background, section three presents the methods used in actualizing the research objectives, section four discusses the performance metric. The results associated with the actualization of the research objectives are presented in section five while section presents the conclusion.

## 2. Related Works

This section reviews some relevant works carried out and published by other researchers. This indicates the extent of the work in this area of research and the techniques and tools used to resolve the signal degradation problem in Nigeria.

Aremu et al. (2015) studied the characterization of signal loss due to dense fog in optical wireless communication systems in Ibadan, southwestern Nigeria. The study shows that under dense fog conditions, when the visibility is less than 500m, the attenuation of the signal takes on the same value for both the 850nm and 1550nm windows. Therefore, the research concludes that atmospheric attenuation is independent of the wavelength at reduced visibility of less than 500m. However, this research only considered dense fog conditions, which are not the predominant weather condition in tropical regions like Nigeria. The present research considered haze and rain, which are more common in the study area.

Falodun et al., (2019) analyzed visibility effects on the free space Earth-to-Space Satellite Optical Link based on measurement data in Nigeria over five selected locations (Ikeja, Akure, Enugu, Jos, and Port-Harcourt) in Nigeria. One year achieved visibility data was obtained at the Nigeria Meteorological Agency (NIMET), which was used to estimate the specific attenuation caused by fog on FSO communication links in the selected locations. The link margin was deduced in all five areas. The estimated specific attenuation caused by condensation was based on operating frequencies associated with a typical commercial FSO. Their findings show 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 approximately 30.33 dB/km, while Enugu recorded the lowest estimated attenuation of approximately 14.19 dB/km. While this study considered fog condition, the present research considered haze and rain which is common in the study area, being the conditions that severely degrade the performance of FSO propagation link in tropical regions.

Ajewole et al., (2019) investigated fog and rain-induced specific attenuations for terrestrial FSO communication in Akure, Ondo State, Nigeria. Archived visibility and rainfall data have been used to analyzed 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 122.14, 109.96, and 86.91 dB/km at wavelengths of 650, 850, and 1550 nm, respectively. Their result shows that fog-induced specific attenuation generally decreases with increasing optical wavelength. Effects on the link margin analysis considering geometric and fog-induced losses show that the proposed FSO system with a commercial optical transceiver, TereScope 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. This study evaluated the fog and rainfall rate of the study location for one year. The present research considered haze and rain, which are more common in the study area.

Ahmed et al., (2020) investigated the effects of atmospheric conditions on the quality of a free-space optical communication link in Nigeria, using Bauchi as a case study. In their work, Bauchi's average speed (m/s) and altitude (m) were considered to determine the FSOC availability and link coverage distance. Therefore, this research concludes that FSOC can be deployed in Bauchi at a coverage link distance of 6.6km. However, the major meteorological parameters

that severely degrade the performance of FSO, especially in tropical regions, are not considered. The present research considered haze and rain, which are more common in the study area.

Ojo et al., (2022) examined the characteristics of fog-induced attenuation for optimizing optical propagation links in Nigeria. Their research aims to characterize Fog-Induced Attenuation (FIA) seasonally and yearly at the selected wavelengths of 850nm, 1300 nm, and 1550nm over the selected locations in Nigeria (Abuja, Ikeja, Jos, Port Harcourt, Ilorin, Markurdi, and Sokoto). Their findings show that a minimal FIA of 0.4 dB/km can be achieved at 1550 nm/193 THz for optimal link planning and design of FSO communication links in Nigeria. Therefore, the study concludes that the general results are essential for the optimal design and budgeting of FSO networks in the study locations considered. However, they did not consider the significant FSOC link scattering factors that severely affect the FSO performance in tropical regions like Nigeria.

From the reviewed related works, it is evident that research on FSOC channel characterization and modeling, as well as the effects of atmospheric weather conditions in FSOC systems, is ongoing because these conditions vary from one geographical location to another. Furthermore, it is clear that several research projects have been carried out across Nigeria, but to the best of my knowledge, there has been no empirically based study of FSO availability completed in Zaria and its environs. Therefore, in this work, a holistic approach will be deployed considering the strategic position of the study area which hosts the only aviation training school in the country, in order to analyze the FSOC system availability practically under the weather conditions available in the study area. This will serve as a reference for future link establishments and research.

## 2.1 Theoretical Review

The theoretical background review relevant to this research work is discussed in this section.

### 2.1.1 Haze and Visibility

Hydrometeors and other particles that are distributed in the atmosphere generate particulate matter, which is called haze. The scattering coefficient is used to evaluate the haze on FSO systems, which is affected by the visibility conditions. Similarly, it is used to calculate atmospheric attenuation. In low-visibility haze conditions, the particle sizes are larger than the average visibility. So, scattering and attenuation are easily triggered in low visibility conditions (Anis et al., 2018).

The meteorological visibility range is the distance a parallel luminous beam travels through the atmosphere until its intensity drops to 2% of its original value. Similarly, meteorological visibility is the distance at which transmittance falls to a specific value ( $\epsilon$ ). It is measured with an instrument called the transmissometer. Three commonly used empirical models (Kruse, Kim, and Al-Naboulsi models) employ visibility information for modeling FSOC channels (Al-Gailani et al., 2021).

### 2.1.2 Rain

Rain is the condensation of water falling from a cloud. It is a natural phenomenon that has both temporal and spatial variability. There are two types of rain: convective rain and stratiform rain. In most cases, rain occurs in the tropics in the form of cells, which comprises both convective and stratiform rains, accounting for about 70% or more of the total rain in most cases. Convective rains have associated features that characterize them, such as high rain rates and short durations. Two primary sub-division of convective rain are showers and thunderstorms. Shower rainfall is characterized by high rainfall intensities ranging from 25–120 mm/hr (Ajewole et al., 2019). In tropical climates, snow does not exist; fog is not a considerable concern, whereas haze and heavy rain are foreseen to significantly impact the availability of an FSO link (Al-Gailani et al., 2021). The typical raindrop size distribution adopted by the International Telecommunication Union (ITU-R) for tropical climates is the Charbonneau rain attenuation model. The atmospheric loss due to rain in terms of its precipitation rate is expressed as shown in equation (1) (Ajewole et al., 2019):

$$Att_{rain} = (a \times R_{pt}^b) L_d \tag{1}$$

$R_{pt}$  shows the intensity of rain (mm/h) 'a' and 'b' are called the power law parameters. The power law parameters are temperature and frequencies dependent which are modeled based on the climate of a region. Table 1 shows the power law parameters for the rain attenuation prediction models proposed by ITU-R for FSO (H. Hussein & Ali 2020):

Table 1: Rain attenuation prediction model proposed by ITU-R for FSO.

Model	Origin	a	b
Charbonneau	France	1.076	0.67
JAPAN	Japan	1.58	0.63

### 2.1.3 Geometrical Attenuation

Beam divergence is one of the geometrical effects in FSO that can make a loss of signal. This loss is due to the spreading of the laser beams between the transmitters to the receiver. In an FSO system, beam divergence must be considered seriously to avoid high signal loss. The wide beam divergence can easily receive the signal without worrying about mis-pointing, but the signal losses are more than small beam divergence. The beam spreads to a size larger than the receiver's aperture; most energy is lost. By increasing the receiver's aperture area, the telescope could collect more light, reducing geometric loss. The geometric path loss is present for all FSO links, and must always be considered when planning any FSO link (Roussat et al., 2015). Even in clear atmospheric weather conditions, the beam diverges, and as a result, the detector receives less signal power. The attenuation due to transmit beam spreading with increasing range is called geometrical attenuation as shown in equation (2) (Mushtaq et al., 2018):

$$Att_{geo} (dB) = -10 \log \left[ \frac{d_r^2}{(d_t + (\theta L)^2)} \right] \tag{2}$$

Where:

- $d_r$  and  $d_t$  are the aperture diameter of the receiver and the transmitter
- " $\theta$ " is the beam divergence angle and
- $L_d$  is the link distance.

## 3. Research Methodology

In this research, archived visibility data (2020–2021) for Zaria and its environs, obtained from the Nigeria Meteorological Agency (NIMET) Zaria station, located at the Nigeria College of Aviation Technology, Zaria (NCAT), was used to characterize and estimate the range and availability of the FSO propagation link in the study area. Table 2 presents the averaged visibility, and Table 4 shows the archived rainfall rate data for the period considered.

Table 2: Average Visibility data of Zaria and its Environs

Year 2020												
Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Visibility (km)	7.1	7.8	9.5	9.3	9.4	9.4	8.0	7.9	8.0	9.6	8.8	7.0
Year 2021												
Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Visibility (km)	7.3	7.2	8.9	9.5	9.4	9.0	8.4	8.7	8.2	9.0	8.0	7.2
Average Visibility	7.2	7.5	9.2	9.4	9.4	9.2	8.2	8.3	8.1	9.3	8.4	7.1

The Cumulative Mean Value (CMV) of the recorded visibility data of the whole months for the period considered for this research was determined to be 8.4km using equation (3).

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \tag{3}$$

where,  $\sum_{i=1}^n x$  is the sum of observations and 'n' is the total number of observations.

The International Visibility Code (IVC) for different weather conditions is presented in Table 4 as recommended by the International Telecommunication Union-Radio (ITU-R). As a result, the amount of haze in the atmosphere indicates the level of atmospheric visibility.

Table 3: Average rainfall precipitate data of the study area (Zaria and its Environs)

Year 2020				
Month	June	July	August	September
Rainfall Rate (mm/hr)	20.3	35.1	26.1	34.1
Year 2021				
Month	June	July	August	September
Rainfall Rate (mm/hr)	22.3	33.3	25.1	34.5
Average Rain fall (mm/hr)	21.3	34.2	25.6	34.3

The cumulative mean of the obtained rainfall rate of the study area of the whole months for the period considered for the research work was determined to be 28.9mm/hr.

Table 4: International Visibility Code Table for Different Weather Conditions (ITU-R)

Weather Conditions	Visibility
Dense fog	0 -50m
Thick fog	50 – 200m
Moderate fog	200 – 500m
Light fog	500 – 1km
Very light fog	1 – 2km
Haze	2 – 4km
Light haze	4 – 10km
Clear air	10 – 20km
Very clear air	20 – 50km
Exceptionally clear	>50Km

### 3.1 Development of the FSOC Model of Zaria and its Environs

To model the atmospheric attenuation of an optical signal, characteristics of the atmospheric conditions must be present. A useful weather parameter that does well in encompassing atmospheric conditions is visibility data. An increase in the presence of atmospheric particles decreases the visibility measured, and thus visibility correlates directly with attenuation as shown in equation (4) transforming atmospheric visibility, and wavelength of the beam, into specific attenuation (Anis *et al.*, 2018):

$$\alpha_{(\lambda)} = 10 \log \left[ e^{\left[ \left( \frac{3.91}{V} \right) \left( \frac{\lambda}{550 \text{nm}} \right)^{-q(v)} * L \right]} \right] \tag{4}$$

where;

“V” is the visibility in km

e is Euler’s constant

$\lambda$  is the transmission wavelength in nm and  
 $q$  is the specific atmospheric attenuation visibility coefficient

The steps involved in the development of the FSO channel mathematical attenuation model are discussed in the following subsections:

### 3.1.1 Attenuation Coefficients of Zaria and its Environs

FSOC systems make use of a 2% transmittance threshold. As such, the value is used with the measured visibility data and the three optical wavelengths (850, 950, and 1550 nm) selected for this study to calculate the attenuation coefficients of the study area using the Kruse model as shown in equation (5) (Al-Gailani *et al.*, 2021):

$$\sigma(\lambda) = \frac{3.91}{V} \left( \frac{\lambda}{550\text{nm}} \right)^{-q} \tag{5}$$

where;

$\lambda$  is the transmission wavelength in nm and  
 $q$  is the specific atmospheric attenuation visibility coefficient  
 $\sigma$  is the attenuation coefficient

The values of the index ‘q’ depend on visibility ranges as shown in equation 6

$$q = \begin{cases} 1.6 & \text{if } V > 50\text{km} \\ 1.3 & \text{if } 6 < V < 50\text{km} \\ 0.585V^{1/3} & \text{if } V < 0.5\text{km} \end{cases} \tag{6}$$

The empirical model has been improved by many researchers, however, in this research work, the Kruse model has been chosen among the existing models, because the model proved that different wavelengths can be used for the HIA over all the visibility ranges.

The Kruse model as shown in equation (7) (Ojo *et al.*, 2022):

$$\gamma_{HIA}(\lambda) = \frac{10\log_{10}T_{th}}{V(\text{km})} \left( \frac{\lambda}{\lambda_o} \right)^{-q} \tag{7}$$

where the transmittance threshold (2 % or 5 %) is represented by  $T_{th}$ . It should be noted that 2 % is used in optical communication systems and 5 % is used in airports to measure the runway visual range. However, a transmittance threshold of 2 % and measured  $V$  were used in this research work. The parameter  $\lambda_o$  is the wavelength relating to the maximum spectrum of the solar band which is 550 nm (Ojo *et al.*, 2022).

Equation (7) may serve as the practical empirical model for the characterization of HIA along with the FSO transmission link. This can be concluded for different climatic regions under the circumstances of disparity in the visibility information of a particular region.

### 3.1.2 Atmospheric Transmittance

The transmittance of laser radiation that has propagated a distance of  $L$  is related to the attenuation coefficient as described by Beer-Lambert law in the following equation (Anis *et al.*, 2018):

$$\tau = \exp(-\sigma L) \tag{8}$$

where;

$\tau$  is the atmospheric transmittance  
 $\sigma$  is the extinction coefficient also known as the attenuation coefficient  
 $L$  is the distance or the link range.

### 3.1.3 Atmospheric Attenuation due to Measure Visibility Data

The atmospheric attenuation ( $\alpha$ ) in dB that the FSOC beam experience during propagation through the atmosphere is calculated using the following equation (Nur & Safa, 2016):

$$\alpha = 10\log_{10}(\tau) \tag{9}$$

The developed Mathematical Attenuation Model of Zaria based on the measured visibility data of the study location with reference to equation (4) is given in equation (10) , and the developed Mathematical Attenuation Model of Zaria based on the measured rainfall rate data with reference to equation (1) is given in equation (11):

$$HIA_{za} = 10\log \left[ e^{\left[ \left( \frac{3.91}{8.4} \right) \left( \frac{\lambda}{550nm} \right)^{-1.3} * L \right]} \right] \tag{10}$$

$$RIA_{za}(dB) = (1.067 \times 28.9^{0.67})L_d \tag{11}$$

## 4. System Performance Metric

The single most significant parameter in evaluating and describing the performance of an FSO link is the link margin. This is the amount of light received by a terminal over and above what is required to keep the link active.

### 4.1 FSO Link Margin Analysis

In designing a reliable FSOC system and quantifying the performance of an FSO link, one crucial task of a good communication system designer is to carry out link margin analysis. This analysis simply entails the inclusion of all known power loss sources into the transmitting power, to ensure a certain minimum power reaches the receiver on the other end of the link (Ajewole *et al.*, 2019). The values of the LM analysis are determined to evaluate the performance of the FSOC propagation link. The formulated LM equation is given in equation 12:

$$LM(dB) = P_t + |S_r| - Att_{geo} - HIA_{za} \tag{12}$$

Since the experimental scenario of FSOC link was not performed in this study, the implementation of the FSOC links was done with the help of parameters of commercial FSO systems (TereScope 5000) available in the local market for this work to carry out a realistic link analysis to estimate and optimize the FSOC propagation link performance in the study area. Table 5 presents the typical link Design specifications adopted for this research work.

Table 5: Adopted FSOC design specifications (TereScope 5000)

Parameter	TereScope 5000 FSO System Specification
Wavelength	830-860nm
Transmit power	85mW
Receiver sensitivity	-46dBm
Transmit aperture diameter	3cm
Receiver aperture diameter	10cm
Beam divergence angle	2mrad

### 5. Results and Discussion

Figure 1 shows the estimated specific attenuation at 850, 950, and 1550 nm wavelengths based on a 2% transmittance threshold against daily visibility for two years using the Kruse model. The graph shows the influence of different optical wavelengths on the computed Haze Induced Attenuation (HIA) at the selected transmission windows. At 2km, the attenuations are 2.366, 1.979, and 1.052dB while at 10km; the attenuations are 11.487, 9.914, and 5.258dB at 850nm, 950nm, and 1550nm respectively. The result shows that the 1550nm optical transmission window has the minimum haze-induced attenuation compared with 850nm and 950nm. This indicates the fact that in FSO systems operating in tropical regions like Zaria, Nigeria, a 1550nm wavelength with an equivalent frequency of 193 GHz is recommended for optimal performance. Table 6 presents the summary of the atmospheric attenuation due to haze in dB.

Table 6: Atmospheric Attenuation in dB due to haze at 850nm, 950nm and 1550nm

Link distance (km)	850nm	950nm	1550nm
1	1.146	0.991	0.526
2	2.366	1.979	1.051
3	3.439	2.976	1.574
4	4.584	3.958	2.104
5	5.735	4.951	2.628
6	6.402	5.935	3.152
7	8.013	6.925	3.675
8	9.172	7.932	4.202
9	10.315	8.928	4.724
10	11.487	9.914	5.258

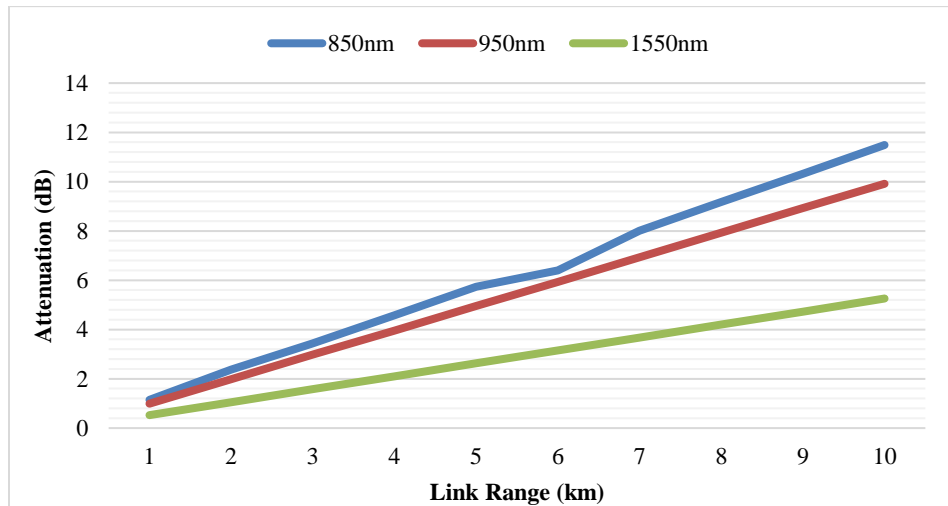


Figure 1: HIA for Different Wavelengths Using Kruse Model

Another analysis carried out in this study was the analysis of the internal design specification of the adopted FSO system because the performance of the FSO link depends upon the atmospheric weather conditions as well as the system design specifications. Geometrical attenuation due to transmit beam spreading with increasing link distance is directly related to the system design specifications. The values of geometrical attenuation are generated using equation 2 concerning the adopted FSO design specifications (TereScope 5000 Transceiver Unit) to determine their effects on the performance of the FSO propagation link in the study area. Figure 2 is a plot of Geometrical Attenuation ( $G_{att}$ ) against the propagation link distance using the data presented in Table 7. From Figure 2 it is observed that the geometrical



attenuation contributes to signal losses. Similarly, the graph clearly shows that, geometrical attenuation varies along with the link distance

Table 7: Geometrical Attenuation in dB for the Adopted FSO System Specification

Link Range (km)	(Terescope 5000) FSO System
1	26.15
2	32.11
3	35.61
4	38.10
5	40.00
6	41.60
7	42.94
8	44.10
9	45.12
10	46.03

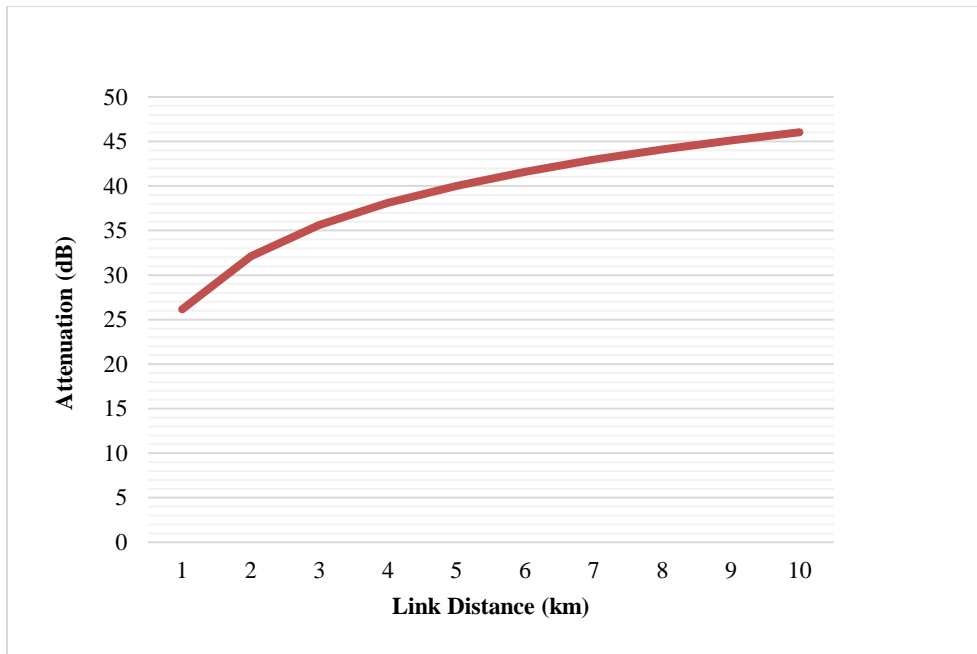


Figure 2:  $G_{att}$  against Propagation Link Range (TereScope 5000)

The expected performance of the FSO system is evaluated through LM analysis under the weather conditions of Zaria Geographical Area of Kaduna State, Nigeria in other to determine the maximum link coverage distance in the study area before system establishments and installations.

The first scenario considered in the link margin analysis is the combined effects of geometric attenuation and atmospheric loss due to  $HIA_{za}$ . Figure 3 is a plot of LM due to the combined effects of  $G_{att}$  and  $HIA_{za}$ . From Figure 3, it is observed that at a 2 km distance, the link margins are 30.82, 31.21, and 32.17dB, at an increased link distance of 5km, the link margins are 19.56, 20.21, and 22.67 at 850, 950, and 1550 nm wavelengths respectively. The results depict the dependency of LM of the FSO link on the propagation link distance at considered wavelengths of 850nm, 950nm, and 1550nm respectively. With a sensitivity of TereScope 5000 being  $-46dBm$ , it is evident from the plots that the LM remains

above the sensitivity of the receiver. Therefore, the FSO link will be available at all the optical wavelengths for the considered propagation link ranges. Table 8 is the estimated link margin for the combine effect of geometrical and haze attenuation in dB.

Table 8: Link margin for the combine effects of geometrical and haze attenuation in dB

Link distance (km)	850nm	950nm	1550nm
1	38.00	38.16	38.62
2	30.82	31.21	32.17
3	26.25	26.71	28.12
4	22.62	23.24	25.10
5	19.56	20.21	22.67
6	17.30	17.77	20.55
7	14.35	15.44	18.69
8	12.03	13.27	16.90
9	9.87	11.25	15.46
10	7.78	9.36	15.01

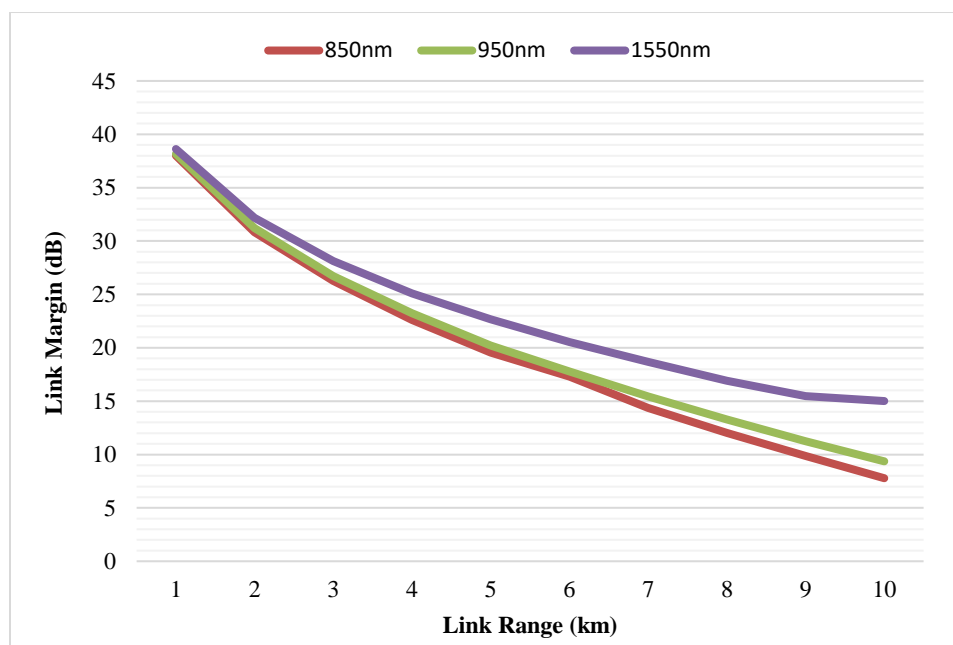


Figure 3: LM for the combined effect of  $G_{att}$  and HIA

The second scenario considered all the factors that contribute to the total attenuation of the FSO propagation channel in the LM analysis for performance evaluation of the adopted FSOC system for this study. Figure 4 is the plot of LM due to the combined effects of  $G_{att}$ ,  $HIA_{za}$ , and  $RIA_{za}$  while table 9 shows the values of the link margin for the combine effects of haze, rain and geometrical losses in dB. It is observed that, at the 2 km link range, the link margins are 10.00, 10.89, and 11.86 dB at 850, 950, and 1550 nm wavelengths respectively. At an increased link distance of 6 km, the link margins reduced to -43.66, -43.20, and -40.41 at 850, 950, and 1550 nm wavelengths respectively. With a sensitivity of -46dB, a beam divergence angle of 2mrad, and a receiver aperture diameter of 10cm, the FSO link will be available at all the selected wavelengths at the propagation link distance of 6km. However, at an increased link distance of 7 km, the link margins reduced to -56.77, -55.69, and -52.44dB at the same set of the transmission windows selected respectively.

Concerning the receiver's sensitivity to the adopted FSO design specifications, the results reveal that the system will be unavailable at all the selected wavelengths. Therefore, it is evident from the plots that 1550nm has the highest LM compared to 850nm and 950nm. This result implies that the use of higher operating wavelength becomes vital as the link range increases.

Table 9: Link margin for the combine effects of haze, rain and geometrical losses in dB

Link distance (km)	850nm	950nm	1550nm
1	27.84	27.90	28.46
2	10.00	10.89	11.86
3	-4.23	-3.77	-2.36
4	-18.02	-17.40	-15.54
5	-31.24	-30.51	-28.19
6	-43.66	-43.20	-40.41
7	-56.77	-55.69	-52.44
8	-69.25	-68.01	-64.28
9	-81.58	-80.19	-75.98
10	-93.82	-92.24	-87.59

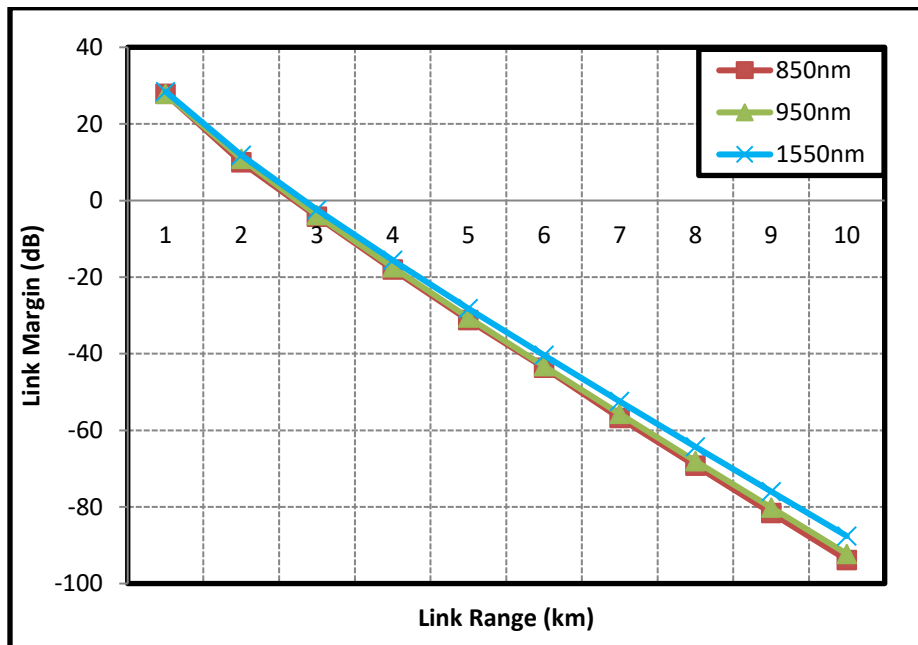


Figure 4: Plots of the LM due to the Combined Effects of  $G_{att}$ , RIA, and HIA

The results of performance evaluation from the LM analysis for the combined effects of  $G_{att}$ ,  $HIA_{za}$ , and  $RIA_{za}$  being the worst scenario of the study area show that transmission at a higher optical wavelength of 1550nm reduces attenuation on the FSO link. Therefore, operating a 1550nm wavelength in transmission power will greatly improve optical transmission links when compared with 850nm and 950nm wavelengths. Furthermore, the robustness of this system is thus confirmed for propagation link distance up to 6km at a wavelength of 1550nm. The general results are highly fundamental and vital for the optimal design and budgeting of FSO networks in the Zaria geographical location of Kaduna State, Nigeria.

## 6. Conclusion

In this research study, specifically induced attenuation caused by both haze and rainfall rates on FSOC link in the Zaria geographical area was investigated using two years of measured visibility data and rainfall rate data obtained from the Nigerian Meteorological (NIMET) agency, Zaria station, located at the Nigeria College of Aviation Technology (NCAT) Zaria and the Center for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria have been investigated for a terrestrial point-to-point. The retrieved visibility and rainfall rates data have been used to compute specifically induced attenuations at three optical wavelengths (850nm, 950nm, and 1550nm). The characterization of the FSOC channel for the study area based on the considered period of visibility and rainfall data has been presented. This characterization is crucial for optimal design and budgeting for a good-quality signal over the FSOC channel. HIA has been deduced using measured visibility data based on the Kruse model and RIA using the Carbonour model. The influence of both HIA and RIA on the optical transmission windows has been carried out to deduce the appropriate one(s) with the best performance under the terrible atmospheric weather conditions of the study location. The results revealed a significant decreasing trend with an increasing link range. The haze-induced attenuation obtained at 850nm, 950 nm, and 1550nm is 5.934dB, 6.402dB, and 3.152dB respectively. Therefore, the result shows that the 1550 nm wavelength has the lowest haze-induced attenuation compared to 850nm and 950nm at a propagation link distance of 6km. The results also show that using a 1550 nm wavelength in designing and implementing the FSOC system in the study area will greatly improve optical transmission links when compared with 850 and 950 nm wavelengths. The overall outcome of the research concludes that FSO has the robustness to handle successful wireless communication during usual weather conditions in Zaria throughout the year for link lengths of up to 6km.

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