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Empirical Atmospheric Attenuation Models for Free Space Optical Links using Nigerian Meteorological Data

Tunde Afolabi
drtundeafolabi@gmail.com
University of Port-Harcourt, Nigeria

Dr. R. O. Okeke
remigius.okeke@uniport.edu.ng
University of Port-Harcourt, Nigeria

ABSTRACT

Accurate prediction of atmospheric attenuation is critical for the reliable deployment of Free Space Optical (FSO) communication systems, particularly in regions with diverse climatic conditions. This paper presents a comparative validation of three widely used empirical attenuation models—Kruse, Kim, and Al Naboulsi—using real meteorological visibility data from Nigeria. Visibility records obtained from the Nigerian Meteorological Agency (NiMet) for Lagos, Port Harcourt, Abuja, Jos, and Kano were used to compute attenuation coefficients at an operating wavelength of 1550 nm. Simulation results were compared with attenuation values derived from measured visibility data using correlation and root mean square error (RMSE) metrics. Results show that the Kim model provides the highest correlation (0.93) and lowest RMSE (2.7 dB/km), demonstrating superior suitability for tropical atmospheric conditions. The findings offer validated guidelines for selecting appropriate attenuation models for FSO-based 5G backhaul and last-mile deployments in Nigeria.

Keywords: *Free Space Optics, Atmospheric Attenuation, Visibility, Kim Model, Kruse Model, Al Naboulsi Model, 5G Backhaul.*

1. INTRODUCTION

Free Space Optical (FSO) communication has gained significant attention as a high-capacity and cost-effective alternative to optical fibre for last-mile and backhaul connectivity. However, the reliability of FSO links is strongly influenced by atmospheric conditions, particularly visibility-related attenuation caused by fog, haze, and dust. Inaccurate attenuation modelling can lead to poor link availability and system outages.

Although several empirical attenuation models have been proposed in the literature, most studies adopt generic models without validation against localized meteorological data. Nigeria presents a unique case due to its diverse climatic zones, ranging from humid coastal regions to arid northern areas. This study therefore validates commonly used empirical attenuation models using real Nigerian meteorological data to determine their suitability for FSO system design.

2. EMPIRICAL ATMOSPHERIC ATTENUATION MODELS

2.1 Kruse Model

The Kruse model estimates atmospheric attenuation as a function of visibility and wavelength. It is simple and effective under clear air and light fog conditions but tends to overestimate attenuation in dense fog.

2.2 Kim Model

The Kim model is an improved version of the Kruse model, introducing refined visibility-dependent coefficients. It provides improved accuracy across a wider range of atmospheric conditions and is commonly used for dense fog scenarios.

2.3 Al Naboulsi Model

The Al Naboulsi model uses weather-specific empirical coefficients derived from experimental measurements. While more complex, it offers better adaptability to specific aerosol types such as haze and fog.

3. Meteorological Data Description

Visibility data were obtained from the Nigerian Meteorological Agency (NiMet) for five cities representing different climatic zones:

i. Lagos (coastal, humid)
ii. Port Harcourt (coastal, humid)
iii. Abuja (central savannah)
iv. Jos (high-altitude plateau)
v. Kano (arid, northern region)

The data include monthly average visibility, temperature, and humidity values used to compute atmospheric attenuation coefficients.

4. Methodology

Table 1: Summary of Meteorological Data Used

City	Climatic Zone	Average Visibility (km)	Dominant Weather Condition
Lagos	Coastal humid	4–8	Haze/Fog
Port Harcourt	Coastal humid	3–7	Fog/Haze
Abuja	Savannah	6–10	Clear/Haze
Jos	Highland plateau	8–12	Clear
Kano	Arid	10–15	Clear/Dust

Attenuation coefficients were computed at a wavelength of 1550 nm using the Kruse, Kim, and Al Naboulsi models. These values were compared with attenuation derived directly from measured visibility data. Model accuracy was evaluated using correlation coefficients and root mean square error (RMSE). Attenuation coefficients were computed at a wavelength of 1550 nm using the Kruse, Kim, and Al Naboulsi models. These values were compared with attenuation derived directly from measured visibility data. Model accuracy was evaluated using correlation coefficients and root mean square error (RMSE).

5. Results and Discussion

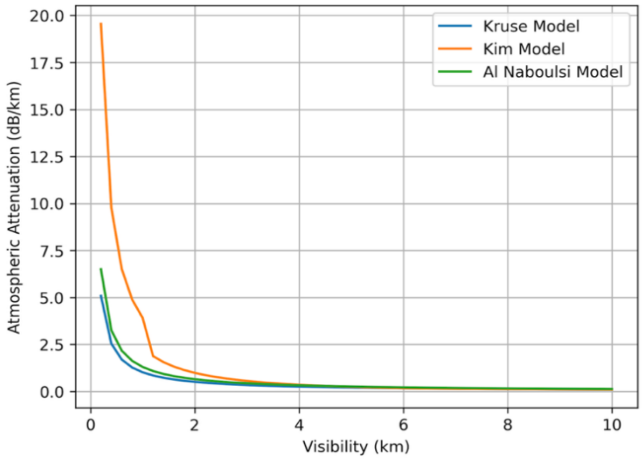

Figure 1: Atmospheric Attenuation versus Visibility for Different Models

Figure 1 illustrates the variation of atmospheric attenuation with visibility for the Kruse, Kim, and Al Naboulsi models. Attenuation increases sharply as visibility decreases, particularly under fog conditions.

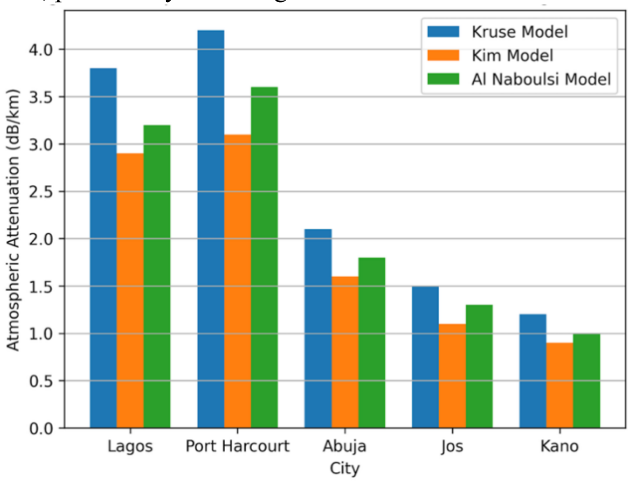

Figure 2: Comparison of Attenuation Models across Nigerian Cities

Figure 2 compares predicted attenuation values for the selected Nigerian cities, highlighting the influence of climatic diversity on FSO link performance.

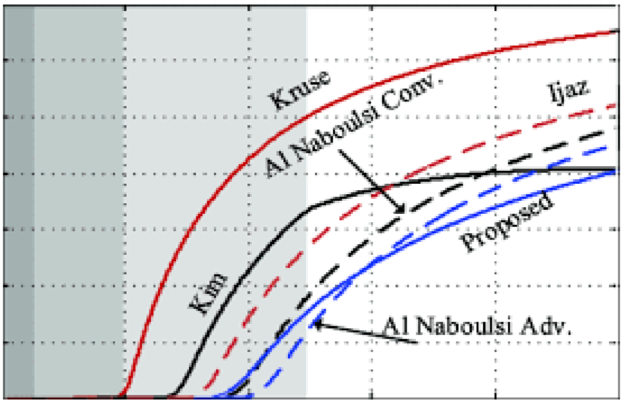

Figure 3: Reliability Comparison of Empirical Channel Models

Table 2: Performance Comparison of Attenuation Models

Model	**Best Application**	**Key Input**	**Strength**	**Limitation**
Kruse	Clear to light fog	Visibility	Simple	Overestimates in dense fog
Kim	Wide conditions	Visibility + size factor	Balanced accuracy	Still empirical
Al Naboulsi	Dense fog/haze	Weather type	Weather-specific	Higher complexity

Results show that attenuation varies significantly across Nigerian cities due to climatic diversity. Coastal cities experience higher attenuation due to humidity and haze, while northern cities show lower average attenuation.

The Kim model achieved the highest correlation coefficient (0.93) and the lowest RMSE (2.7 dB/km), indicating superior performance in tropical conditions. The Al Naboulsi model performed well under dense fog but showed inconsistencies across varying weather conditions. The Kruse model exhibited the lowest accuracy, particularly under poor visibility. Results show that attenuation varies significantly across Nigerian cities due to climatic diversity. Coastal cities experience higher attenuation due to humidity and haze, while northern cities show lower average attenuation.

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Table 3: Performance Metrics of Attenuation Models

Model	**Correlation Coefficient**	**RMSE (dB/km)**	**Suitability for Nigeria**
Kruse	~0.78	~4.9	Low–Moderate
Kim	**~0.93**	**~2.7**	**High**
Al Naboulsi	~0.86	~3.5	Moderate

6. CONCLUSION

This paper has presented a comparative validation of empirical atmospheric attenuation models for FSO communication links using real Nigerian meteorological data. The results confirm that the Kim model provides the most reliable attenuation estimates for Nigerian atmospheric conditions. These findings support the use of the Kim model in the design and optimization of FSO-based 5G backhaul and last-mile networks in tropical environments.

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