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On the applicability of some existing tropospheric scintillation prediction models for Ikeja and Abuja, Nigeria

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ABSTRACT

Tropospheric scintillation which causes rapid fluctuation of signal due to the turbulence in the atmosphere is of significance in satellite link budget design. Existing models that predict the intensity of scintillation such as Karasawa, International Telecommunication Union Radiocommunication (ITU-R) Sector, Otung, Van de Kamp and Ortgies are not appropriate for predicting scintillation intensity (SI) in Nigeria due to localization of the models to particular regions. The monthly average air temperature and relative humidity for Ikeja and Abuja, Nigeria, retrieved from the Nigerian Meteorological Centre data bank were used for the investigation. An elevation angle of 5° was used as look angle, antenna diameter of 0.3 m, 40 GHz and 45 GHz frequencies were considered in this study. The existing scintillation model values were then compared with the measured values for the two locations to determine the best performance model. The SI results at 40 GHz and 45 GHz were obtained for each of the existing models. It could be deduced from the results obtained that orgies model values were the most closet to the measured values. Therefore, Orgies-N model was the most appropriate for SI prediction in Ikeja and Abuja.

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1. INTRODUCTION

Tropospheric scintillation occurs due to signal fluctuations resulting from variation in density of the atmosphere caused by turbulent mixture of air mass. It is also triggered by temperature inversion and change in level of humidity at different layers of the atmosphere. Scintillation caused by atmospheric disturbances is dependent on location, time, frequency and exists on line of site links and more pronounced on earth-space paths at frequencies above 10 GHz [1]. According to [2], tropospheric scintillation can either result into destructive interference of signals which could affect the availability of low fade margin systems that required tracking systems and fade mitigation techniques. Scintillation occurrence is constant regardless of the condition of the sky whether it is clear or raining [3]. Thus, its effects must be taken into consideration for the design of link budgets in low fade margin systems especially for satellite systems operating at narrow frequency bandwidths, also those at high frequencies and low elevation angles [4]. There are a number of scintillation prediction models proposed to investigate the severity of scintillation in satellite communication. These include Karasawa model, International Telecommunication Union (ITU) model, Otung model, Van de Kamp model and Ortgies models which are based on data collected from countries like Japan, Germany, Finland, United Kingdom, United States. These are geographical locations with a four-season climate (spring, summer, autumn and winter). These models may not be appropriate when used in tropical country like Nigeria that has a two-season climate (rainy and dry season) and are characterized by high humidity, uniform temperature and ample rainfall. This is because Nigeria's climate pattern is different as compared to the four seasons' countries. The investigation of severity of scintillation and how it affects satellite communication in tropical regions like Nigeria has also been carried out [5]–[9]. It could be seen that the various works carried out on tropospheric scintillation in Nigeria are majorly based on the International Telecommunication Union Radiocommunication (ITU-R) model and from works carried out in different regions of the world, the ITU-R model is not necessarily the best model for all regions in determining the severity of scintillation [10]. This makes it rather necessary to determine the preferable model to be used in the Nigerian region. In this study, investigation of the relationship between scintillation and frequency has been carried out, results for the different models are compared with the result obtained experimentally by [11]–[13]. The contributions of this paper are the Orgies N model has been discovered to be the best model applicable to the Nigeria region out of the six scintillation models under study. Also, the wet term refrativities and scintillation intensities (SI) for Abuja and Ikeja, Nigeria, were obtained. The results of this research could be used by satellite communication engineers for accurate planning and setting of links budget during satellite design. The remaining paper is organized as: tropospheric scintillation prediction models are presented in section 2, while section 3 discusses the details of the method used. Section 4 depicts the simulation results with performance comparison, while section 5 concludes the paper.

2. TROPOSPHERIC SCINTILLATION PREDICTION MODELS

As previously discussed, development of different models has been undertaken under diverse conditions and locations. This implies that the suitability of these different models depends on environment of usage and development. The models considered for this study are the Karasawa model, Otung Model, Van De Kamp model, ITU_R model, the Orties T and N models.

2.1. Karasawa model

This model was the first model to integrate meteorological data in its analysis. It is suitable for a four-season geographical location. This model tries to address problem that arises from Comité Consultatif International pour la Radio (CCIR) model. CCIR model's problems lie in the fact that it lacks meteorological element as such, regional and seasonal dependency of scintillation cannot be determined with the model and also because CCIR model works best at an elevation angle of 1 degree. The scintillation intensity for Karasawa model σ_{kar} is given by [14] as in (1):

$$\sigma_{kar} = 0.0228(0.15 + 5.2 \times 10^{-3} N_{wet}) f^{0.45} \sqrt{\frac{GD_m}{\sin\theta^{1.3}}} \text{ dB} \quad (1)$$

where G, θ, N_{wet}, D_m and f are antenna gain factor, elvation angle, humidity, antenna diameter and frequency, respectively. If θ is <5°, then $\sin\theta$ is replaced with $\sin\theta + \sqrt{sin^2\theta + 2h/R_e}$ where h and R_e are height and effective earth radius, respectively. The effective antenna diameter D_{eff} is given by (2):

$$D_{eff} = \sqrt{\eta D_m} \quad (2)$$

where η is aperture efficiency. The N_{wet} depends on temperature T, saturation water vapor pressure, *es*, Humidity H and is given in (3).

$$N_{wet} = \frac{3{,}732}{(273+T)^2} H.esD_{eff} = \sqrt{\eta D_m} \quad (3)$$

$$es = 6.112 \exp\left(\frac{19.70T}{273+T}\right)(KPa) \quad (4)$$

The meteorological input parameters must be averaged over a period of about a month so that the model does not predict short-term scintillation variations with daily weather changes [14].

2.2. ITU-R model

The model is based on indirect measurements with the data used for its development obtained from the ITU-R data bank [15]. It is suitable for prediction of scintillation on a link with elevation angles in the range of 4° to 32°, antenna diameters between 3 and 36 m, and frequency range of 7 to 14 GHz. (ITU-R

P.618-12 [11]–[17]. The model adopts the same basic formulation as the Karasawa model with its long-term scintillation variance expressed as corresponded to $Nwet$, which is a function of relative humidity H (%) and temperature t ($°C$), measured at ground level. The scintillation intensity for ITU-R model σ_{ITU-R} is given by ITU-R P.618-12 [15] as in (5).

$$\sigma_{ITU-R} = \frac{\sigma_{ref}\, f^{\frac{7}{12}} g_{(x)}}{(\sin\theta)^{1.2}} \tag{5}$$

σ_{ref} is the referenced scintillation intensity given by (6).

$$\sigma_{ref} = 3.6 \times 10^{-3} + N_{wet} \times 10^{-4}\, dB \tag{6}$$

The antenna averaging factor g (x) is given in (7):

$$g(x) = \sqrt{3.86(x^2 + 1)^{\frac{11}{12}} \times \sin\left(\frac{11}{6}\tan^{-1}\frac{1}{x}\right) - 7.08x^{\frac{5}{6}}} \tag{7}$$

where, x depends on L as given in (8); and define in (9).

$$x = 1.22\frac{{D_{eff}}^2 \times f}{L} \tag{8}$$

$$L = \frac{2 \times h_l}{\sqrt{\sin\theta^2 + 2.35 \times 10^{-4}} + \sin\theta} \tag{9}$$

2.3. Otung model

This model follows the same variation as the ITU-R model with their difference arising in the elevation angle exponent. The scintillation intensity for the Otung model σ_{otu} is given by [18] as in (10).

$$\sigma_{otu} = \frac{\sigma_{ref}\, f^{\frac{7}{12}} g_{(x)}}{(\sin\theta)^{\frac{11}{12}}} \tag{10}$$

The values for the antenna averaging factor, and referenced scintillation intensity follows the same formulation as that of the ITU-R model.

2.4. Van de kamp model

Van de Kamp also adapted the same variation as the ITU-R model in his prediction model but slightly changed the elevation angle and frequency exponent [19]–[22]. It also enhances the ITU-R model by including both the surface layer and cloud scintillation. It was discovered from his research that scintillation events are also influenced by the presence of large cumulus cloud crossing the satellite path [23], [24]. The scintillation intensity for the Van de Kamp model σ_{van} incorporating W_{hc} is given by [11]–[13] as:

$$\sigma_{van} = \frac{\sigma_{ref}\, f^{0.45} g_{(x)}}{(\sin\theta)^{1.3}} \tag{11}$$

$$\sigma_{ref} = 0.98 \times 10^{-4}\,(N_{wet} + Q)\, dB \tag{12}$$

$$Q = -39.2 + 56W_{hc} \tag{13}$$

2.5. Ortgies model

This research is aimed at proposing a new model that can be used in slant-path. The Ortgies-N and Ortgies-T models derived from the Olympus experiment data assumed that short term scintillations follow a normal probability density function (PDF) and long-term scintillation follows lognormal probability density function [25]–[27]. The Ortgies N model makes use of the wet term component, and Ortgies T model uses the mean surface temperature in its predictions. The scintillation intensities for the Ortgies N model σ_{orn} and Ortgies T modelσ_{ort} are given by [20] and [22] as in (14) and (15),

$$\ln{\sigma_{orn}}^2 = \ln(g(x).f^{1.21}(\sin\theta)^{-2.4}) - 12.5 + 0.0462\, N_{wet} \tag{14}$$

$$\ln \sigma_{ort}{}^2 = \ln(g(x).f^{1.21}(\sin\theta)^{-2.4}) - 12.5 + 0.0865T \quad (15)$$

3. RESEARCH METHOD

The meteorological factors such as air temperature and relative humidity for the scintillation prediction models were sourced from the Nigeria Meteorological Centre data bank. The monthly average of relative humidity and air temperature data for Abuja and Ikeja over a period of 5 years were used. These meteorological factors were taken to obtain the cumulative average for the whole range of dataset, and monthly maximum, average and minimum for each month for the respective locations. In this paper, the average maximum and minimum temperatures were used to calculate maximum and minimum scintillation, respectively. The monthly maximum and minimum N_{wet} were also calculated using the average maximum and minimum temperatures, with the monthly average relative humidity. This research assumed the earth station antenna efficiency of 0.5 and antenna diameter of 0.3m, the earth station diameter used as the hub station of very small aperture terminal (VSAT) configuration. An elevation angle of 5° was used because low elevation angle causes signal to travel through atmosphere resulting in more scintillation. The simulation of each scintillation prediction model was done for two frequencies 40 GHz and 45 GHz. To validate the research, a comparison was made with an experimental result obtained in [10] which studied the propagation impairments for fixed satellite communication links at the microwave frequencies in Nigeria". The two datasets were used during the course of this study; measured result obtained by [10] and the meteorological data (air temperature and relative humidity) used as inputs to scintillation prediction models.

3.1. Variation of wet term of refractivity

The monthly variation of maximum, average and minimum wet terms of refractivity N_{wet} were determined using (3). The maximum and minimum N_{wet}, are the values of N_{wet} calculated using the maximum and minimum monthly temperatures, respectively, and the average N_{wet}, is the value of N_{wet} obtained from the average monthly temperature. This procedure was repeated for Abuja and Ikeja.

3.2. Scintillation prediction modelling

The long-term averages of relative humidity (H) and temperature t (°C) which show the specific climatic conditions of the site were used to prevent the averages of temperature and relative humidity fluctuating with season, scintillation intensity distributions displayed seasonal variations. This could also be predicted by using seasonal averages of *t* and *H* in this method. Input parameters required for the scintillation prediction model are:

Average surface ambient temperature "t" (°C) at the site
average surface relative humidity "H"(%) at the site
frequency "f" (GHz),
path elevation angle "θ", where θ≥5°
physical diameter "D" (m) of the earth-station antenna
antenna efficiency "η", η=0.5 is a conservative value if unknown.
height of turbulence "h"

The following steps were taken to simulate scintillation prediction model:
- Step 1: The wet term of the radio refractivity, N_{wet}, which corresponds to *es*, *t* and *H* was computed using (3) as given in recommendation ITU-R P.453.
- Step 2: The effective antenna diameter, D_{eff}, from the geometrical diameter, *D*, and the antenna efficiency η, was calculated using (2).
- Step 3: The antenna averaging factor was obtained using (7)
- Step 4: The effective path length L was found using (9)
- Step 5: The reference scintillation intensity of the signal amplitude was determined.
- Step 6: The scintillation Intensity of the signal for the considered period and frequency was then calculated using the appropriate equation as given by the models.

Steps 1 to 6 were repeated for each of the models using the appropriate equations.

4. RESULTS AND DISCUSSION

The wet term of refractivities for the Abuja and Ikeja at 40 GHz and 45 GHz frequencies were determined using Nigerian meteorological center data. The values obtained are then presented in Figures 1 and 2. Also, the scintillation intensities for the two locations are also shown in Figures 3 and 4.

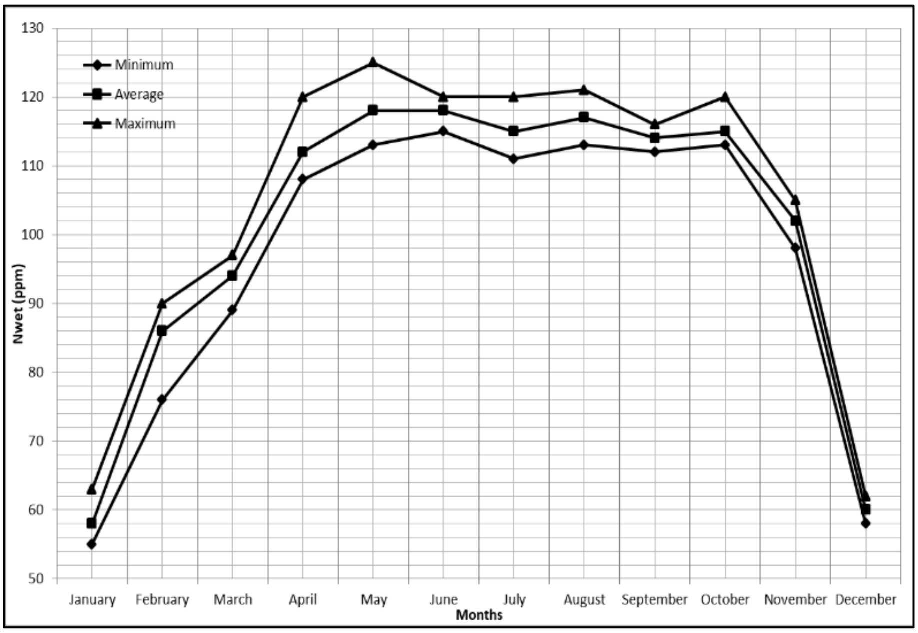

Figure 1. Wet term refractivity 'N_{wet}'for Abuja

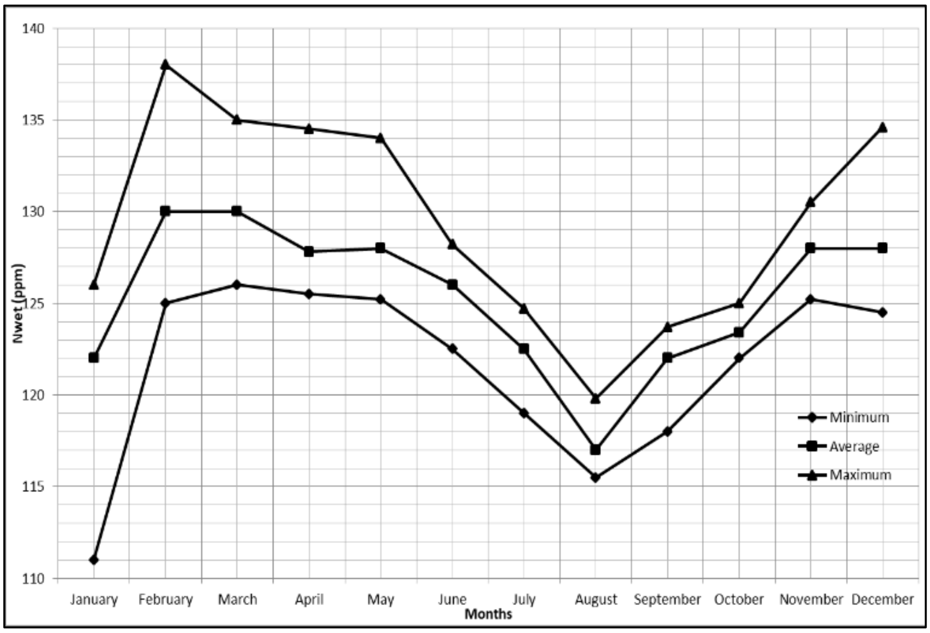

Figure 2. Wet term refractivity 'N_{wet}'for Ikeja

4.1. Wet term of refractivity

The maximum and minimum values of N_{wet} obtained for Abuja were 119.96 ppm and 61.66 ppm, respectively corresponding to the month of May and January, respectively. The maximum and minimum values of N_{wet} at Ikeja were 138.32 ppm and 119.52 ppm, respectively, corresponding to the month of February and January, respectively. The average values of N_{wet} for Ikeja were significantly higher than that of Abuja, this suggests that the magnitude of scintillation experienced for Ikeja was greater than the Abuja. The wet term of radio refractivity showed a significant variation throughout the year observed with time as shown in Figures 1 and 2. This is due changing pattern of temperature and humidity. The maximum N_{wet} was the N_{wet} at maximum average temperature, minimum N_{wet}, was the N_{wet} at minimum average temperature and the average N_{wet}, was the N_{wet} at average temperature.

4.2. Scintillation intensities for Abuja and Ikeja

The SI obtained in Abuja at 40 GHz and 45 GHz for Karasawa, ITU-R, VanDe Kamp, Ortgies N, Ortgies T, Otung and measured values were 0.897, 0.946; 2.000, 2.455; 2.145, 2.297; 2.469, 2.650; 1.125, 1.208; 1.148, 1.229; 3.211, 3.345; respectively. While the corresponding SI values obtained for Ikeja at 40 GHz and 45 GHz were 1.058, 1.116; 2.592, 2.775; 2.520, 2.698; 3.800, 4.080; 1.082, 1.621; 1.229, 1.390; 4.042, 4.322; for Karasawa, ITU-R, VanDe Kamp, Ortgies N, Ortgies T, Otung and measured, respectively. These results are contained in Tables 1 and 2; and also presented in Figures 3 and 4. It can be deduced from the SI obtained that Ortgies N model gave the SI values closest to the measured values, while Karasawa model gave the largest deviation from the measured values. Also, the SI values increased with frequency. The variation of scintillation intensity at frequency of 40 GHz showed that radio signals experienced maximum and minimum tropospheric scintillations in the month of May and December, respectively at Abuja for all the models considered. While the maximum and minimum tropospheric scintillations were experienced in March and August, respectively, at Ikeja. The Ortgies T model predicted that maximum and minimum scintillation occurred at the two locations in March and August, respectively. The results obtained revealed that, at 45 GHz, satellite communications experienced maximum and minimum tropospheric scintillations in March and August, respectively at Ikeja for all the models considered.

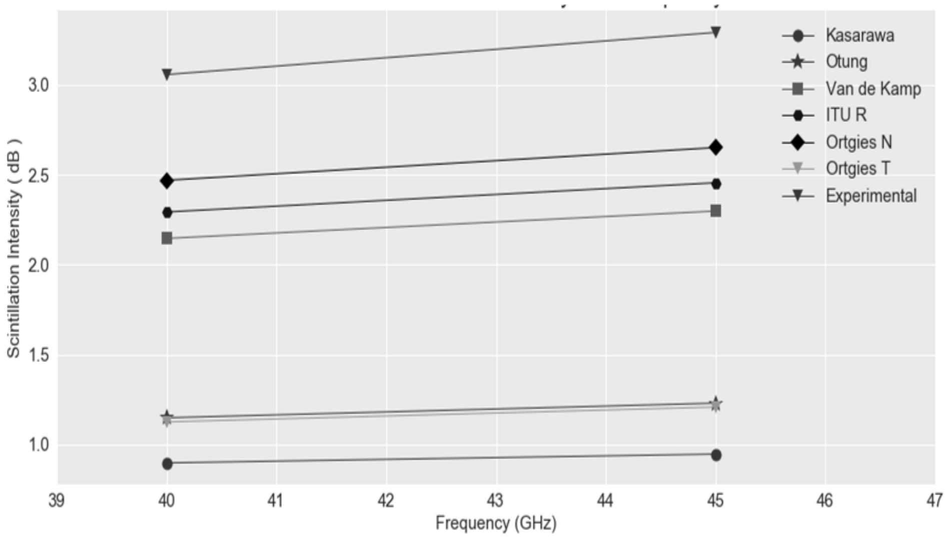

Figure 3. Scintillation intensity versus frequency for various scintillation models considered at Abuja

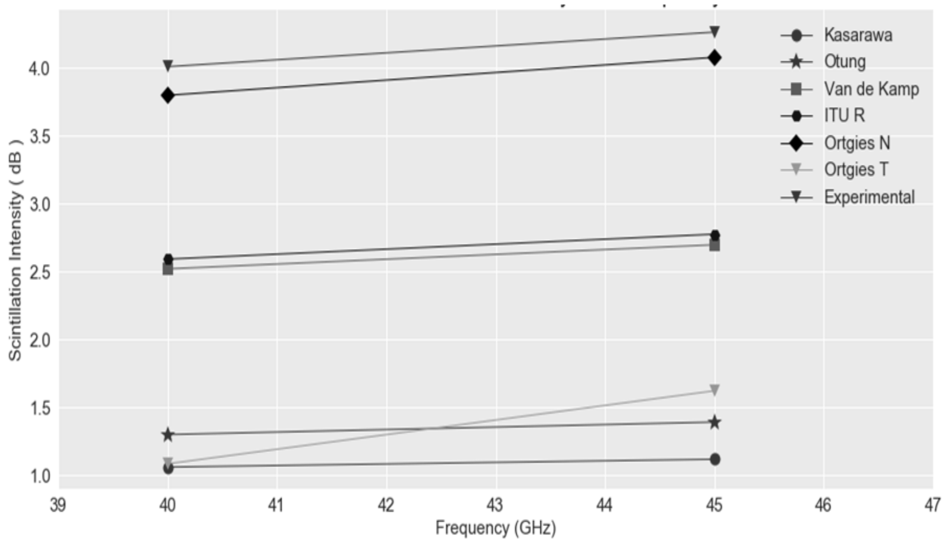

Figure 4. Scintillation intensity versus frequency for various scintillation models considered at Ikeja

Table 1. Scintillation intensity results for Abuja at frequencies 40 GHz and 45 GHz

Scintillation Prediction Models	Frequency	
	40 GHz	45 GHz
Karasawa	0.897	1.058
ITU-R	2.292	2.592
Van De Kamp	2.145	2.520
Ortgies N	2.469	3.800
Ortgies T	1.125	1.082
Otung	1.148	1.229
Experimental	3.211	4.042

Table 2. Scintillation intensity results for Ikeja at frequencies 40 GHz and 45 GHz

Scintillation Prediction Models	Frequency	
	40 GHz	45 GHz
Karasawa	0.945	1.116
ITU-R	2.455	2.775
Van De Kamp	2.297	2.698
Ortgies N	2.650	4.080
Ortgies T	1.208	1.621
Otung	1.229	1.390
Experimental	3.345	4.322

5. CONCLUSION

In this study, an investigation of the applicability of some scintillation models such as Karasawa, Otung, ITU-R, Van de Kamp, Ortgies N and Ortgies model for Ka-Band on satellite communication link in Nigeria was carried out. The wet term refractivity for Ikeja and Abuja using meteorological factors value was computed. This in turn used to determine the SI values for all the models considered with the physical parameters of the antenna. Comparison was made among the models with the experimental one to determine the best (most) suitable for satellite communication link in Nigeria for accurate planning. The results obtained revealed that Ortgies N model gave the closest SI values to measured values and therefore, the best for predicting SI in Nigeria.

REFERENCES

[1] L. J. Ippolito, *Satellite Communications Systems Engineering: Atmospheric Effects, Satellite Link Design and System Performance*. John Wiley&Sons, Ltd, 2008, doi: 10.1002/9780470754443.

[2] H. Vasseur, "Prediction of tropospheric scintillation on satellite links from radiosonde data," *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 2, pp. 293–301, 1999, doi: 10.1109/8.761069.

[3] M. Singh, J. Singh, S. Idris, S. Hassan, and F. Ain, "Measurement of tropospheric scintillation from satellite beacon at ku-band in South East Asia," *Journal of Computer Science*, vol. 7, no. 2, pp. 251–254, 2007.

[4] C. E. Mayer, B. E. Jaeger, R. K. Crane, and X. Wang, "Ka-band scintillations: Measurements and model predictions," in *Proceedings of the IEEE*, Jun. 1997, vol. 85, no. 6, pp. 936–945, doi: 10.1109/5.598416.

[5] O. Agunlejika, T. I. Raji, and Adeleke O. A, "Tropospheric scintillation prediction for some selected cities in Nigeria's tropical climate," *International Journal of Basic and Applied Sciences (IJBAS)*, vol. 9, no. 10, pp. 12–19, 2010

[6] B. G. Ayantunji, A. Adamu, and K. Orisekeh, "Tropospheric influences on satellite communications in tropical environment : a case study of nigeria," *International Journal of engineering and Innovative Technology*, vol. 2, no. 12, pp. 111–116, 2013

[7] T. V. Omotosho, S. A. Akinwumi, M. R. Usikalu, O. O. Ometan, and M. O. Adewusi, "Tropospheric scintillation and its impact on earth-space satellite communication in Nigeria," in *2016 IEEE Radio and Antenna Days of the Indian Ocean*, Oct. 2016, doi: 10.1109/RADIO.2016.7772041.

[8] M. Hossain and M. Samad, "The tropospheric scintillation prediction of earth-to-satellite link for Bangladeshi climatic condition," *Serbian Journal of Electrical Engineering*, vol. 12, no. 3, pp. 263–273, 2015, doi: 10.2298/sjee1503263h.

[9] S. A. Akinwumi, T. V. Omotosho, M. R. Usikalu, T. A. Adagunodo, M. O. Adewusi, and O. O. Ometan, "Analysis and comparison of tropospheric scintillation prediction models at Covenant University," in *IOP Conference Series: Earth and Environmental Science*, Jul. 2018, vol. 173, no. 1, doi: 10.1088/1755-1315/173/1/012015.

[10] T. V. Omotosho, "Studies of propagation impairments for fixed satellite communication links at the microwave frequencies in Nigeria," Ph.D. dissertation, Covenant University Ota, 2008.

[11] I. F. Elshami, J. Din, L. H. Yin, and A. I. Elgayar, "Characterization of concurrent Ku band tropospheric scintillation and rain attenuation in Malaysia," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 15, no. 2, pp. 956–961, Aug. 2019, doi: 10.11591/ijeecs.v15.i2.pp956-961.

[12] J. Herrera, M. Priore, D. Mekonnen, and K. Deshpande, "Tropospheric scintillation signatures: observations of the possible effect thunderstorms have on GPS signals," in *Discovery Day*, 2019, pp. 5–13.

[13] A. Pinho, S. Mota, and A. Rocha, "A quick overview of a new scintillation database," *ITU Journal: ICT Discoveries*, vol. 2, no. 1, 2019.

[14] Y. Karasawa, M. Yamada, and J. E. Allnutt, "A new prediction method for tropospheric scintillation on earth-space paths," *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 11, pp. 1608–1614, 1988, doi: 10.1109/8.9712.

[15] ITU-R, "Propagation data and prediction methods required for the design of Earth-space telecommunication systems," *Recommendation ITU-R P.618-8*, vol. 12. pp. 1–24, 2015.

[16] I. Dahman, P. Arbogast, N. Jeannin, and B. Benammar, "Rain attenuation prediction model for satellite communications based on the Météo-France ensemble prediction system PEARP," *Natural Hazards and Earth System Sciences*, vol. 18, no. 12, pp. 3327–3341, Dec. 2018, doi: 10.5194/nhess-18-3327-2018.

[17] S. Das, M. Chakraborty, S. Chakraborty, A. Shukla, and R. Acharya, "Experimental studies of ka band rain fade slope at a tropical location of India," *Advances in Space Research*, vol. 66, no. 7, pp. 1551–1557, Oct. 2020, doi: 10.1016/j.asr.2020.06.014.

[18] I. E. Otung, "Prediction of tropospheric amplitude scintillation on a satellite link," *IEEE Transactions on Antennas and Propagation*, vol. 44, no. 12, pp. 1600–1608, 1996, doi: 10.1109/8.546246.

[19] M. M. J. L. Van De Kamp, J. K. Tervonen, E. T. Salonen, and J. Pedro V Polares Baptista, "Improved models for long-term prediction of tropospheric scintillation on slant paths," *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 2, pp. 249–260, 1999, doi: 10.1109/8.761064.

[20] N. A. Rahim, H. N. A. Mulop, and K. Badron, "Study of tropospheric scintillation effects in Ku-band frequency for satellite communication system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 3, pp. 3136–3144, Jun. 2020, doi: 10.11591/ijece.v10i3.pp3136-3144.

[21] C.-S. Lu *et al.*, "A new rain attenuation prediction model for the earth-space links," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 10, pp. 5432–5442, Oct. 2018, doi: 10.1109/TAP.2018.2854181.

[22] M. A. Samad, F. D. Diba, and D.-Y. Choi, "A survey of rain attenuation prediction models for terrestrial links—current research challenges and state-of-the-art," *Sensors*, vol. 21, no. 4, Feb. 2021, doi: 10.3390/s21041207.

[23] M. N. Ahuna, T. J. O. Afullo, and A. A. Alonge, "Rain attenuation prediction using artificial neural network for dynamic rain fade mitigation," *SAIEE Africa Research Journal*, vol. 110, no. 1, pp. 11–18, Mar. 2019, doi: 10.23919/SAIEE.2019.8643146.

[24] M. A. Samad, F. D. Diba, and D.-Y. Choi, "A survey of rain fade models for earth–space telecommunication links—taxonomy, methods, and comparative study," *Remote Sensing*, vol. 13, no. 10, May 2021, doi: 10.3390/rs13101965.

[25] M. Marchese, A. Moheddine, and F. Patrone, "IoT and UAV integration in 5G hybrid terrestrial-satellite networks," *Sensors*, vol. 19, no. 17, Aug. 2019, doi: 10.3390/s19173704.

[26] P. M. Kalaivaanan, A. Sali, R. S. A. Raja Abdullah, S. Yaakob, M. Jit Singh, and A. M. Al-Saegh, "Evaluation of Ka-Band rain attenuation for satellite communication in tropical regions through a measurement of multiple antenna sizes," *IEEE Access*, vol. 8, pp. 18007–18018, 2020, doi: 10.1109/ACCESS.2020.2966873.

[27] G. Ortgies, "Prediction of slant-path amplitude scintillations from meteorological parameters," in *International Symposium on Radio Propagation*, 1993, pp. 218–221.

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