EVALUATION OF SPATIAL DISTRIBUTION OF RAIN ATTENUATION FOR GEOSYNCHRONOUS SATELLITE LINKS WITH EARTH STATION LOCATIONS ACROSS NIGERIA

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***Abstract*— In this paper, evaluation of spatial distribution of rain attenuation for geosynchronous satellite links with earth station locations across Nigeria is presented. The International Telecommunication Union (ITU) model, rain attenuation for satellite links was used to determine the rain attenuation as a function of the link's elevation angle and earth station's latitude. The case study satellite was Nigcomsat 1R, a geostationary satellite with orbital longitude of 42.48°.The study was conducted for the Ka frequency band. Particularly, for the earth station, one State from each of the six geopolitical zones in Nigeria was selected for the study. The rainfall data was used along with the geo-coordinates of the earth station locations and the geo-coordinates of the GEO satellite to determine elevation angle, and then the effective rain path length and the rain attenuation for the Ka frequency band. The results of the elevation angles computed showed that the satellite link with earth station in Gombe State has the highest elevation angle of 51.8° and satellite link with earth station in Sokoto State has the lowest elevation angle of 44.6°. On the other hand, the satellite link with earth station in Akwa Ibom State has the lowest effective rain path length of 3.95 km while the satellite link with earth station in Sokoto State has the highest effective rain path length of 4.11 km. Also, Imo State link has the highest rainfall rate of 125 mm/hr as well as highest rain attenuation of 100.9954 dB for the horizontal polarization, 83.00884 dB for the vertical polarization and 91.75047 dB for the circular polarization. On the other hand, Sokoto State link has the lowest rainfall rate of 60 mm/hr hr as well as lowest rain attenuation of 53.15862 dB for the horizontal polarization, 44.6871dB for the vertical polarization and 48.82655 dB for the circular polarization. In all the six earth station-satellite links, the vertical polarization has the lowest rain attenuation while the horizontal polarization has the highest rain attenuation values. In essence, in other to minimize the impact of rainfall on the received signal strength, the vertical polarization should be selected.**

***Keywords*—** Nigcomsat 1R, Geostationary Satellite, Rain Attenuation, Geosynchronous Satellite, Ka Frequency Band, Geo-Coordinates, Signal Polarization, Elevation Angle, Satellite Link

1. INTRODUCTION

NigComSat-1R is Nigeria's geostationary (GEO) satellite with orbital slot of 42.5° East [1,2,3,4,5,6,7]. It is a communication satellite that serves security and social, as well as industrial development purposes for Nigeria and other African sub-regions [8,9,10]. A geostationary satellite orbits round the earth at a fixed longitude at the equator and at an altitude of about 35,786 km [11,12,13,14]. Also, the satellite orbits at the same angular velocity of the earth such that it remains at a fixed position relative to the earth [15,11,171,181,19,20].

In generals, communication satellites links consist of wireless communication uplinks and downlinks that operate mainly in different high frequency microwave bands [21,22,23,24,25,26,27]. Like every other microwave links, the geostationary satellite communication links are affected by rain attenuation. Also, studies have shown that the amount of rain attenuation suffered by satellite signal is a function of the signal frequency, the rain rate, the distance of the rain path, as well as the elevation angle of the satellite link [28,29,30,31,32,33]. While a geostationary satellite has a fixed location relative to the earth station, different earth stations have different rainfall rates and elevation angles relative to a given GEO satellite. As such, the rain attenuation suffered by the satellite signal from different earth stations to a given GEO satellite differs. In this paper, the variation in rain attenuation of the satellite-earth links for six (6) different locations in Nigeria and the NigComSat-1R GEO satellite is studied. The different locations in Nigeria are selected one location from each of the six (6) geopolitical zones in Nigeria. The effect of signal polarization of the rain attenuation is also studied for the horizontal, vertical and circular polarized satellite signals. The requisite analytical expressions for computing the different parameters relevant to the study are presented and sample numerical examples are presented along with the discussion of the results.

2. METHODOLOGY

According to the International Telecommunication Union (ITU) model, rain attenuation (A_{R}) is generally expressed as [34,35,36,37,38];

$$A_{\mathrm{R}} = \gamma(L_{ef}) \quad (1)$$

Where γ is the specific rain attenuation and L_{ef} is the effective rain path length. In the rain attenuation computation, the cases of circular, horizontal or vertical polarization are considered. The specific rain attenuation, γ is expressed as ;

$$\gamma = \begin{cases} \gamma_v = k_v \, (R_p)^{\alpha_v} & \text{for vertically polarized signal} \\ \gamma_h = k_h \, (R_p)^{\alpha_h} & \text{for horizontally polarized signal} \\ \gamma_c = k_c \, (R_p)^{\alpha_c} & \text{for circular polarized signal} \end{cases} \quad (2)$$

Where the values of the constants, k_c, α_c , k_v, α_v ' k_h and α_h are frequency and polarization dependent. While k_v, α_v , k_h and α_h are provided by ITU, k_c and α_c are computed as follows;

$$k_c = 0.5\,(k_h + k_v) \quad (3)$$

$$\alpha_c = \frac{(k_h)(\alpha_h) + (k_v)(\alpha_v)}{2(k_c)} \quad (4)$$

According to [40,41], the effective rain path length (L_{ef}) is determined as follows;

(i) The rain height, (H_{rain}) is given in terms of the Lat_{est} (the latitude of the earth station)

$$H_{rain} = \begin{cases} 5.0 & for\ 0 \le Lat_{est} \le 23^\circ \\ 5.0 - 0.075(Lat_{est} - 23) & for\ Lat_{est} \ge 23^\circ \end{cases} \quad (5)$$

(ii) Let L_s be the slant path length of the rain, H_{est} be the earth station height and θ_{ele} be the elevation angle of the satellite link, then;

$$L_s = \frac{H_{rain} - H_{est}}{\sin(\theta_{ele})} \quad (6)$$

(iii) Let L_g be the length of L_s when projected horizontal on the ground, then;

$$L_g = (L_s)\cos(\theta_{ele}) \quad (7)$$

(iv) Let r_f be the reduction factor for rain path length, where;

$$r_f = \frac{1}{1 + \left(\frac{L_g}{L_s}\right)} \quad (8)$$

(v) The effective rain path length (L_{ef}) is given as;

$$L_{ef} = L_s(r_f) = \left(\frac{H_{rain} - H_{est}}{\sin(\theta_{ele})}\right)(r_f) \quad (6)$$

$$A_R = \gamma(L_s)(r_f) = \begin{cases} A_{R_v} = \gamma_v(L_s)(r_f) & \text{for vertical} \\ A_{R_h} = \gamma_h(L_s)(r_f) & \text{for horizontal} \\ A_{R_c} = \gamma_c(L_s)(r_f) & \text{for circular} \end{cases} \quad (7)$$

The θ_{ele} of the satellite link can be determined from the central angle (γ) of the satellite link as follows;

$$\cos(\gamma) = \cos(\mathrm{Lat_{sat}})\cos(\mathrm{Lat_{est}})\cos(\mathrm{Long_{sat}} - \mathrm{Long_{est}}) + \sin(\mathrm{Lat_{sat}})\sin(\mathrm{Lat_{est}}) \quad (8)$$

where $Long_{sat}$ and $Long_{est}$ are the longitude of the satellite and earth station respectively, Lat_{sat} is the latitude of the satellite, while h_{sat} is the altitude of the satellite and r_e represents the earth radius . Then;

$$\cos(\theta_{ele}) = \frac{\sin(\gamma)}{\sqrt{\left[1 + \left(\frac{r_e}{r_e + h_{sat}}\right)^2 - 2\left(\frac{r_e}{r_e + h_{sat}}\right)\cos(\gamma)\right]}} \quad (9)$$

Therefore,

$$\theta_{ele} = \mathrm{acos}\left(\frac{\sin(\gamma)}{\sqrt{\left[1 + \left(\frac{r_e}{r_e + h_{sat}}\right)^2 - 2\left(\frac{r_e}{r_e + h_{sat}}\right)\cos(\gamma)\right]}}\right) \quad (10)$$

The study is conducted with rainfall data from six selected States in Nigeria. The dataset of rainfall rates (in mm/hr) exceeded for 0.01% of an average year for the selected study site in Nigeria is given in Table 1. The map plot of the selected study sites across Nigeria is given in Figure 1 while the map plot of the footprint and detail data of the case study Nigcomsat 1R GEO satellite (available at https://www.n2yo.com/?s=38014&live=1) is presented in Figure 2.

In addition, the case study satellite is Nigcomsat 1R, a geostationary satellite with orbital longitude of 42.48°. Nigcomsat 1R has 4 C-band, 14 Ku-band , 8 Ka-band and 2 L-band transponders with which it provides video, voice, data, internet and other application services. The study focused on the higher frequency Ka-band of 26.5 GHz to 40 GHz. Specifically, frequency of 33 GHz is considered.

Table 1 The Dataset of Rainfall rates (in mm/h) exceeded for 0.01% of an average year for selected study sites in Nigeria

S/N	Region	State	Latitude	Longitude	Rainfall rates (in mm/h) exceeded for 0.01% of an average year
1	North West	Sokoto	13.122419	5.206980	60
2	NORTH EAST	Gombe State	10.304326	11.172825	71
3	North Central	Niger State	9.743812	6.132366	84
4	South East	Imo State	5.527823	7.063300	125
5	South South	Akwa Ibom State	4.647675	7.763166	124
6	South West	Ondo State	7.305184,	5.189489	94

Source: https://gpspointplotter.com/

Figure 1 The Map Plot of The Selected Study Sites Across Nigeria

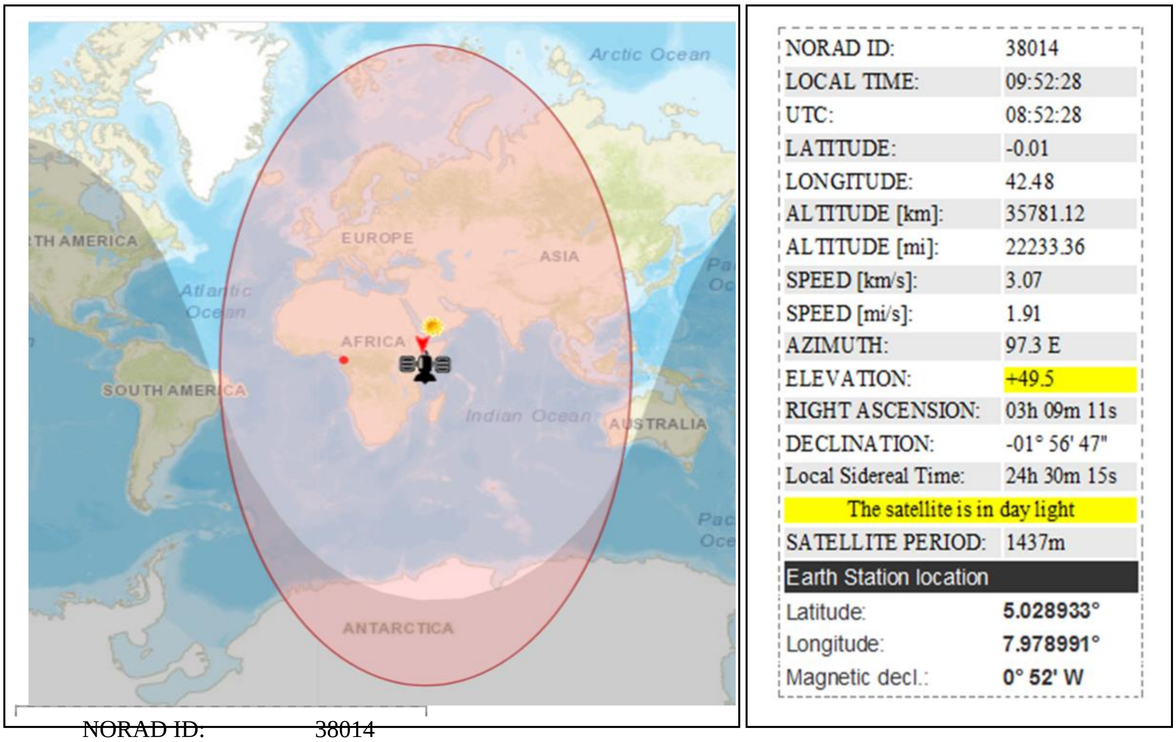

Figure 2 The map plot of the footprint and detail data of the case study Nigcomsat 1R GEO satellite (available at https://www.n2yo.com/?s=38014&live=1)

NORAD ID:	38014
LOCAL TIME:	09:52:28
UTC:	08:52:28
LATITUDE:	-0.01
LONGITUDE:	42.48
ALTITUDE [km]:	35781.12
ALTITUDE [mi]:	22233.36
SPEED [km/s]:	3.07
SPEED [mi/s]:	1.91
AZIMUTH:	97.3 E
ELEVATION:	+49.5
RIGHT ASCENSION:	03h 09m 11s
DECLINATION:	-01° 56' 47"
Local Sidereal Time:	24h 30m 15s

3. RESULTS AND DISCUSSION

The results of the elevation angles computed for the selected study site in Nigeria based on Nigcomsat 1R satellite longitude of 42.48 ° are given in Table 2. The results show that the satellite link with earth station in Gombe State has the highest elevation angle of 51.8° and satellite link with earth station in Sokoto State has the lowest elevation angle of 44.6°. Again, the results of the effective rain path length (L_{ef}) for the selected study site in Nigeria based on Nigcomsat 1R satellite longitude of 42.48° are shown in Table 3. The results show that the satellite link with earth station in Akwa Ibom State has the lowest effective rain path length of 3.95 km while the satellite link with earth station in Sokoto State has the highest effective rain path length of 4.11 km.

Also, the results in Table 3 and Table 4 show that Imo State link has the highest rainfall rate of 125 mm/hr, as well as the highest rain attenuation of 100.9954 dB for the horizontal polarization, 83.00884 dB for the vertical polarization and 91.75047 dB for the circular polarization. On the other hand, Sokoto State link has the lowest rainfall rate of 60 mm/hr, as well as the lowest rain attenuation of 53.15862 dB for the horizontal polarization, 44.6871dB for the vertical polarization and 48.82655 dB for the circular polarization.

Table 2 The results of the elevation angle for the selected study site in Nigeria based on Nigcomsat 1R satellite longitude of 42.48°.

S/N	Region	State	Latitude	Longitude	Rainfall rates (in mm/h) exceeded for 0.01% of an average year	Elevation Angle, $\theta_{ele}(°)$
1	North West	Sokoto	13.122419	5.206980	60	44.6°
2	North East	Gombe State	10.304326	11.172825	71	51.8°
3	North Central	Niger State	9.743812	6.132366	84	46.6°
4	South East	Imo State	5.527823	7.063300	125	48.4°
5	South South	Akwa Ibom State	4.647675	7.763166	124	49.3°
6	South West	Ondo State	7.305184	5.189489	94	46.1°

Table 3 The results of the effective rain path length (L_{ef}) for the selected study site in Nigeria based on Nigcomsat 1R satellite longitude of 42.48°.

State	Rainfall rates (in mm/h) exceeded for 0.01% of an average year	Effective rain path length, L_{ef} **(km)**
Sokoto	60	**4.11**
Ondo State	94	**4.05**
Niger State	84	**4.03**
Imo State	125	**3.97**
Akwa Ibom State	124	**3.95**
Gombe State	71	**3.89**

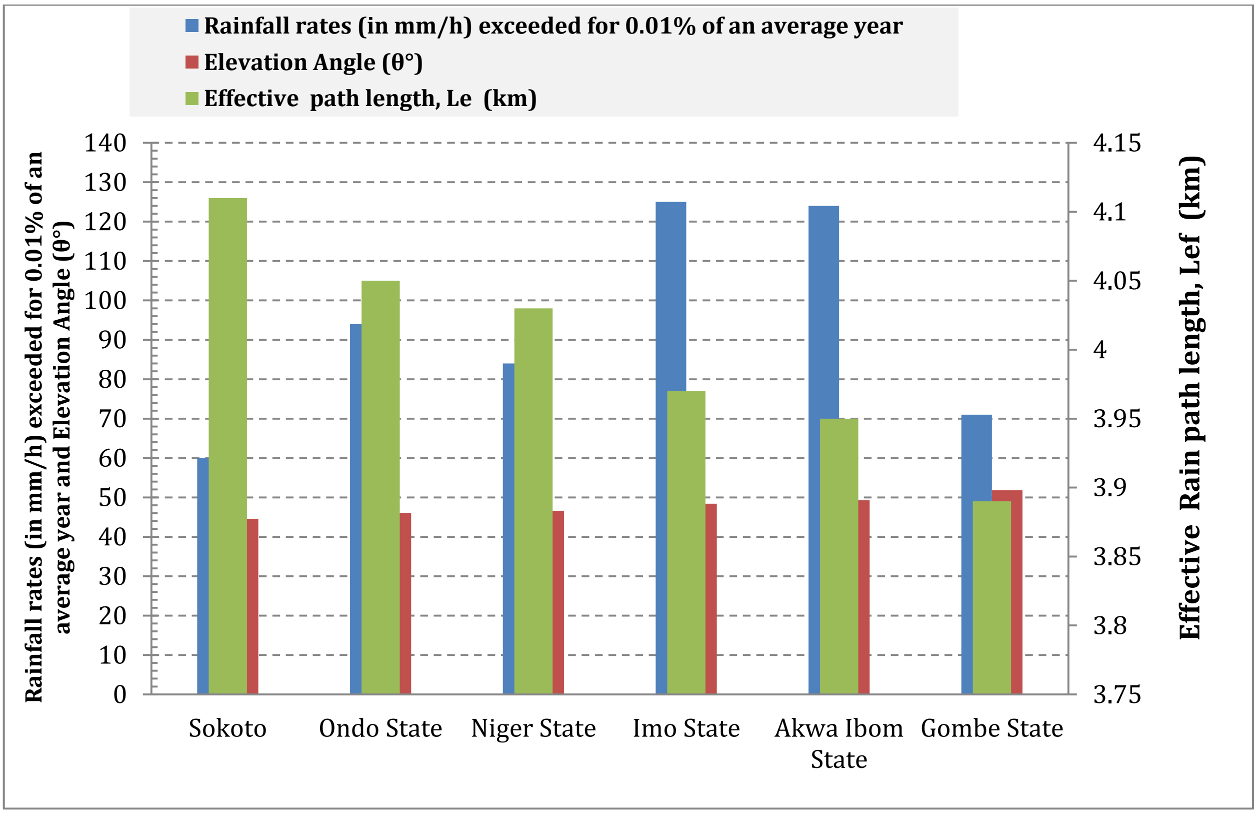

Figure 3 Bar chart of the rainfall rates (in mm/h) exceeded for 0.01% of an average year, the elevation angle (θ°) and the effective rain path length, L_{ef} (km) for the six sites

Table 4 The results of the rain attenuation (for horizontal polarization) in dB for p = 0.01%, rain attenuation (for vertical polarization) in dB for p = 0.01%, rain attenuation (for circular polarization) in dB for p = 0.01%

State	Rainfall rates (in mm/h) exceeded for 0.01% of an average year	**Elevation Angle (θ°)**	**Rain Attenuation (horizontal** polarization**) in dB for p = 0.01%**	**Rain Attenuation (vertical** polarization**) in dB for p = 0.01%**	**Rain Attenuation (circular** polarization**) in dB for p = 0.01%**
Sokoto State	60	**44.6**	53.15862	44.6871	48.82655
Gombe State	71	**51.8**	58.67392	49.06923	53.75665
Niger State	84	**46.6**	71.07884	59.13747	64.95811
Ondo State	94	**46.1**	79.20315	65.66973	72.26094
Akwa Ibom State	124	**49.3**	99.59188	81.87544	90.48629
Imo State	125	**48.4**	100.9954	83.00884	91.75047

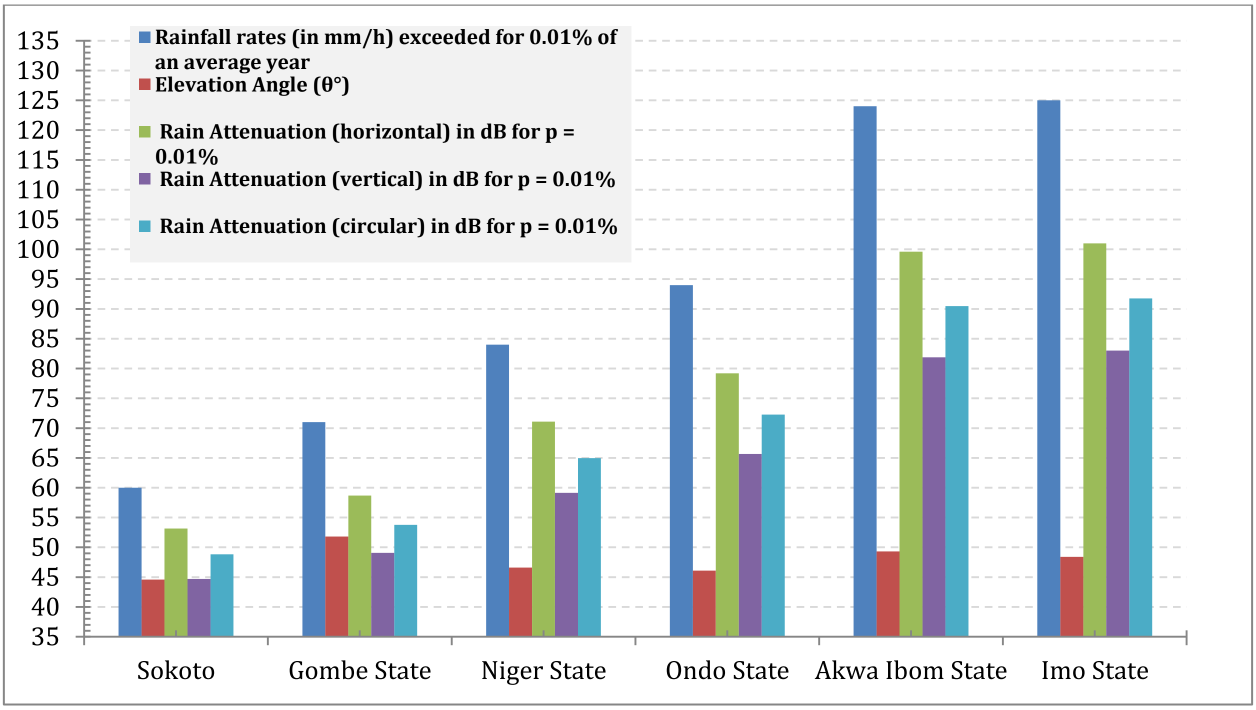

Figure 5 The bar chart of the rainfall rates (in mm/h) exceeded for 0.01% of an average year, elevation angle (θ°), rain attenuation (horizontal) in dB for p = 0.01%, rain attenuation (vertical) in dB for p = 0.01%, rain attenuation (circular) in dB for p = 0.01%

4. CONCLUSION

Rain attenuation is computed for six GEO satellite earth links. The case study satellite is the Nigcomsat 1R while the earth stations are selected from the six geopolitical regions in Nigeria. The study computed the elevation angle of each of the satellite, the effective rain path length and the rain attenuation using available analytical expressions. The results are then used to evaluate the distribution of rain attenuation for the GEO satellite communication links with earth stations located in the different regions of Nigeria with different rainfall statistics. In all, the results showed that the regions in the Southern part of Nigeria have higher rainfall rate and hence higher rain attenuation. Also the horizontal polarized signals suffer more rain attenuation than the circular and vertically polarized signals.

REFERENCES

1. LAWAL, E. D. L. S., & Center, O. S. (2021). Federal Ministry of Communications and Digital Economy.
2. Rügamer, A., & Seybold, D. (2018, May). Multi-GNSS Measurement Campaign in Southeast Asia using the MGSE-System. In *2018 European Navigation Conference (ENC)* (pp. 9-18). IEEE.
3. Lasisi, E. D. L. S. (2018). UPDATE ON NIGERIAN SATELLITE AUGMENTATION SYSTEM.
4. Мельник, А. М. (2020). SATELLITE SEGMENT OF NATIONAL INFORMATION INFRASTRUCTURE. APPROACHES TO IMPLEMENTATION. *Сборник научных трудов «Цифровые технологии»*, (28), 14-46.
5. Rügamer, A., & Seybold, D. (2018, May). Multi-GNSS Measurement Campaign in Southeast Asia using the MGSE-System. In *2018 European Navigation Conference (ENC)* (pp. 9-18). IEEE.
6. Nosaze, O. (2019). Dining with the Tiger: Towards a Critique of the Sino-Nigeria Partnership. *Available at SSRN 3468968*.
7. Ajiboye, A. T., & Ibiyemi, T. S. (2017). PID Controller Performance Evaluation in Distributed Mobile Telemedicine Nodes within Nigeria. *Ilorin Journal of Computer Science and Information Technology*, *2*(1), 18-28.
8. Dairo, O. F., & Kolawole, L. B. (2017, November). Statistical analysis of tropospheric scintillation of satellite communication signals using Karasawa and ITU-R models. In *2017 IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON)* (pp. 347-352). IEEE.
9. Simeon, O. (2016) Comparative Analysis Of Rain Attenuation In Satellite

Communication Link For Different Polarization Options.

10. Ojo, J. S., Falodun, S. E., & Odiba, O. (2017). 0 C isotherm height distribution for Earth-space communication satellite links in Nigeria. *Indian Journal of Radio & Space Physics (IJRSP)*, *43*(3), 225-234.
11. Dongfang, W., Baojun, P., & Weike, X. (2017). GEO space debris environment determination in the earth fixed coordinate system. In *7th European Conference on Space Debris. ESA Space Debris Office, Darmstadt, ESOC*.
12. Livingston, W. (2019). Geostationary Satellite over East Africa Observed from Kitt Peak, Arizona. *Bulletin of the American Meteorological Society*, *100*(10), 1877-1880.
13. Dongfang, W., Baojun, P., & Weike, X. (2017). GEO space debris flux determination based on earth-fixed coordinate system. *Acta Astronautica*, *130*, 60-66.
14. Dongfang, W., Baojun, P., & Weike, X. (2017). GEO space debris flux determination based on earth-fixed coordinate system. *Acta Astronautica*, *130*, 60-66.
15. Chopra, K. N. (2020). Satellite Communications, and Mathematical Modeling for Satellite Orbits and Signal Propagation-a Tutorial and short Review. *Latin-American Journal of Physics Education*, *14*(4), 2.
16. Rosengren, A. J., Skoulidou, D. K., Tsiganis, K., & Voyatzis, G. (2019). Dynamical cartography of Earth satellite orbits. *Advances in Space Research*, *63*(1), 443-460.
17. Proietti, S., Flores, R., Fantino, E., & Pontani, M. (2021). Long-term orbit dynamics of decommissioned geostationary satellites. *Acta Astronautica*, *182*, 559-573.
18. Flores, R., Burhani, B. M., & Fantino, E. (2021). A method for accurate and efficient propagation of satellite orbits: A case study for a Molniya orbit. *Alexandria Engineering Journal*, *60*(2), 2661-2676.
19. Felicetti, L., Harkness, P., & Ceriotti, M. (2017). Attitude and orbital dynamics of a variable-geometry, spinning solar sail in Earth orbit.
20. Bolmgren, K., Mitchell, C., Bruno, J., & Bust, G. (2020). Tomographic imaging of traveling ionospheric disturbances using GNSS and geostationary satellite observations. *Journal of Geophysical Research: Space Physics*, *125*(3), e2019JA027551.
21. Singh, K., Nirmal, A. V., & Sharma, S. V. (2017). Link margin for wireless radio communication link. *ICTACT Journal on Communication Technology*, *8*(3).
22. Höyhtyä, M., Corici, M., Covaci, S., & Guta, M. (2019, November). 5G and beyond for new space: Vision and research challenges. In *Proceedings of the International Communications Satellite Systems Conference (ICSSC), Okinawa, Japan* (Vol. 29).
23. Al-Janabi, F., Singh, M. J., & Pharwaha, A. P. S. (2021). Development of Microstrip Antenna for Satellite Application at Ku/Ka Band. *J. Commun.*, *16*(4), 118-125.
24. Kourogiorgas, C., Papafragkakis, A. Z., Arapoglou, P. D. M., Panagopoulos, A. D., & Ventouras, S. (2019, March). Total Atmospheric Attenuation Statistics for LEO Mega-Constellations Operating at Q/V Bands. In *2019 13th European Conference on Antennas and Propagation (EuCAP)* (pp. 1-5). IEEE.
25. Karim, S. R., Sakib, S., Islam, M. T., & Ahamed, F. S. (2018). A Review of Communications Satellite by Focusing on ‘Bangabandhu Satellite-1’, the First GEO Communications Satellite of Bangladesh. *International Journal of Networks and Communications*, *8*(5), 123-128.
26. Fadil, S., & Abuhamoud, N. (2019). (Link Budget of GEO Satellite (Nile Sat) at Ku-band Frequency) Case of study Tripoli and Sebha. *Journal of Pure & Applied Sciences*, *18*(4).
27. Gataullin, Y., & Kozlowski, R. (2009). Implementation of rain and gaseous attenuation models for 26-30 GHz Ka-Band Communication.
28. Giannetti, F., Reggiannini, R., Moretti, M., Adirosi, E., Baldini, L., Facheris, L., ... &

Vaccaro, A. (2017). Real-time rain rate evaluation via satellite downlink signal attenuation measurement. *Sensors*, *17*(8), 1864.

29. Abozeed, M. I., Alhilali, M., Yin, L. H., & Din, J. (2019). Rain attenuation statistics for mobile satellite communications estimated from radar measurements in Malaysia. *Telkomnika*, *17*(3), 1110-1117.
30. Abozeed, M. I., Alhilali, M., Yin, L. H., & Din, J. (2019). Rain attenuation statistics for mobile satellite communications estimated from radar measurements in Malaysia. *Telkomnika*, *17*(3), 1110-1117.
31. Samad, M. A., Diba, F. D., & Choi, D. Y. (2021). A Survey of Rain Fade Models for Earth–Space Telecommunication Links—Taxonomy, Methods, and Comparative Study. *Remote Sensing*, *13*(10), 1965.
32. Yussuff, A. I. O., Hamzat, N., & Khamis, N. H. H. (2017). Site Diversity Technique Application on Rain Attenuation for Lagos. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, *5*(1), 77-84.
33. Brito, J., D'Amico, M., Ramos, B., Núñez, A., & Nolivos, I. (2018, September). Performance of Equatorial Time Diversity Systems Evaluated from Rain Rate Time Series. In *2018 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)* (pp. 750-753). IEEE.
34. Semire, F. A., Mohd-Mokhtar, R., & Akanbi, I. A. (2019). Validation of new ITU-R rain attenuation prediction model over Malaysia equatorial region. *MAPAN*, *34*(1), 71-77.
35. Kalaivaanan, P. M., Sali, A., Abdullah, R. S. A. R., Yaakob, S., Singh, M. J., & Al-Saegh, A. M. (2020). Evaluation of ka-band rain attenuation for satellite communication in tropical regions through a measurement of multiple antenna sizes. *IEEE Access*, *8*, 18007-18018.
36. Nandi, D., Pérez-Fontán, F., Pastoriza-Santos, V., & Machado, F. (2021). Analysis of rain fade characteristics from experimental satellite measurements at Ka/Q bands for a temperate location Vigo, Spain. *Advances in Space Research*.
37. Semire, F. A., Mohd-Mokhtar, R., Adegbola, O. A., & Akanbi, I. A. (2016). Performance evaluation of an improved ITU-R rain attenuation prediction model over Malaysia equatorial region. *LAUTECH Journal of Engineering and Technology*, *10*(2), 133-136.
38. Yuan, F., Lee, Y. H., Meng, Y. S., Yeo, J. X., & Ong, J. T. (2017). Statistical study of cloud attenuation on Ka-band satellite signal in tropical region. *IEEE Antennas and Wireless Propagation Letters*, *16*, 2018-2021.
39. Olatunde, I. D., Babatunde, K. O., & Afolabi, D. O. (2019). Rain attenuation prediction in nigeria using artificial neural network (ann). *International Journal of Electrical and Electronic Science*, *6*(1), 1-7.
40. Ezeh, G. N., Chukwuneke, N. S., Ogujiofor, N. C., & Diala, U. H. (2014). Effects of rain attenuation on satellite communication link. *advances in science and technology research journal*, *8*(22), 1-11.