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Research Article

Rain Induced Cross Polarization on Satellite Communication in Nigeria

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Abstract. Microwave systems performance on satellite communication link operating above 10 GHz is increasingly degraded by rain when designing telecommunication systems. Cross polarization is one of the major source of signal degradation that affectthe frequency reuse when employed to boost capacity of the channel. The effect of cross-polarization in thirty-seven (37) stations in Nigeria were carried out using 10 years data obtained from Nigeria Meteorological Agency (NIMET) at the look angle from Nigeria Communication Satellite (NigComSat). International Telecommunication Union-Recommendation (ITU-R) model was used to for this study. The stations were grouped into six geopolitical zones in Nigeria which are Southwest (SW), Southeast (SE), South-south (SS), Northcentral (NC), Northwest (NW) and Northeast (NE). The results reveal that cross-polarization discrimination (XPD) become very poor as frequency (at Ku-band, Ka-band, V-band) increases especially at lower percentage of time (such as 0.001%, and 0.01%) unavailability. Hence XPD, at all frequencies is poorer in the southern part of Nigeria SE, SS and SW due to high rainfall rate. The results also show that only Northern part of the country will experience no interference at 0.01% as XPD is over 30 dB ITU-R base line for Ku-band transmission. However, for Ka-band and V-band at 0.001% and 0.01% unavailability of time interference will occur in all stations in Nigeria, but at 0.1% and 1% XPD is over 30 dB for all stations. This study will help in the adequate planning and designing of satellite telecommunication expansion in all the six geopolitical zones in Nigeria.

Keywords. Cross-polarization discrimination; Satellite communication; Frequency; Rainfall rate

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1. Introduction

The atmosphere is a typical space in which diverse physical processes occur. The atmosphere, can be defined as the thin layer of gases enveloping the earth. This is a mixture of ideal gases, for example, Nitrogen, (78.09%) Oxygen, (20.9%) carbon dioxide, (0.04%) water vapour, (0.4%) hydrogen, ozone, etc. are all trace gases. Although nitrogen and oxygen have higher volume, but the less dominant gases, are also crucial. The making of the atmosphere is basically from the sun, (David [4]) Land and sea interactions are also crucial. Solar radiation at UV, infrared and visible light wavelength constantly bombards the atmosphere. Tan and Thurai [10] some solar radiations are reflected back to space by clouds, some are scattered back to space by atmospheric gases or absorbed totally or partially by atmospheric molecules, especially ozone and water vapour, leading to the heating of some parts of the atmosphere, in process some escape and gets to the surface of the earth (David [4]).

Attenuation due to rainfall pose an important part in the design of earth-satellite radio links at frequencies above 10 GHz. The rise in the way satellite telecommunication and broadcasting services are being used has demanded the need for earth-space attenuation studies in the tropical regions. The major work on attenuation studies on earth-satellite paths has been carried out in the temperate regions of the world (Ajayi et al. [1]). Aside from the use of 6/4 GHz bands for satellite communication, satellite systems now operate in the 14/12 GHz bands and above, though the use of 30/20 GHz and 50/40 GHz, is very much in use and at advantage (Omotosho [8]).

In the tropical regions, the precipitation characteristics differ from those of the temperate regions, the statistical relationships derived in the temperate regions have not been very suitable for systems design in the tropical regions (Ajayi et al. [1]). The higher frequency bands, the wider its bandwidth and the more susceptible to signal degradation as a result of rain, i.e. radio signals being absorbed by rain, snow or ice crystals (ESA [5]). The performance of Satellite communication in microwave and millimeter wave could greatly degrade as a result of atmospheric phenomena such as, snow, ice, fog, cloud rain, etc. Major source of signal degradation when building an efficient telecom system are cross polarization, outages, and interference caused by scattering (Van de Kamp [11]).

Cross-polarization is defined as the received power polarized orthogonally to the transmitted power, compared to that polarized in same manner as the transmitted power (Saunders [9]) or the ratio of the power in the co-polarized wave (wanted signal) to the power in the cross-polarized wave (unwanted signal) that was sent in the same state (Camara [3]; Brussaard [2]). Cross-polarization of microwave radiation due to transmission through the canted raindrops is of paramount importance, because radio relay systems will use both the vertical and the horizontal polarizations to increase channel capacity (Omotosho [8]). The frequency reuse is a technique often employed to reduce the frequency separation and to maximize spectrum capacity without increasing the spectrum occupancy.

Radio wave energy could be transmitted from one polarization state to the orthogonal polarization state, thereby leading to interference between two channels (Omotosho [8]). Camara, 2015, showed that cross polarization discrimination (XPD) is numerically low when the rain rate increases for frequencies up to 30 GHz, and concluded that XPD is good in the northern and forest part of Guinea. The study of Jaiswal [7] in India, revealed that XPD depends on frequency, co-polar attenuation and rainfall rate.

Therefore, this research is aimed to study the rain induced cross-polarization effect on satellite communication in 37 locations in Nigeria.

2. Method

The study area is situated on the latitudes 3° north and 14° on the east of the Greenwich meridian and on latitudes 4° north of the equator (9.0820° N, 8.6753°E). Nigeria is found in the tropics where the climatic seasons are damp and humid (nnpcgroup [**?**]). Ten years (2006-2016) rainfall rate data used for this work was obtained from Nigeria Meteorological Agency (NIMET) at the satellite look angle to Nigeria communication satellite (NigComSAT-II) for thirty-seven locations in Nigeria as shown in Figure 1. The country is divided into six geopolitical zones which includes, Southwest (SW), Southeast (SE), South-south (SS), Middle belt (MB), Northwest (NW) and Northeast (NE). International telecommunication union recommendation (ITU-R 2015), version P618 was used to compute the cross-polarization discrimination (XPD) in dB.The specific attenuation, copolar attenuation and cross-polarization, for 0.01% of time unavailability, (99.99% available) 0.1% unavailability (99.9% available), 0.001% unavailability, (99.999% available) and 1% unavailability, (99% available) was calculated to predict the total slant path attenuation for other time percentagesat frequencies of 12-50 GHz. Matlab and Excel was used to compute and process the results.

The following methods estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 55 GHz. The following parameters are required:

$R_{0.01}$	:	point rainfall rate for the location for 0.01% of an average year (mm/h)
h_s	:	height above mean sea level of the earth station (km)
O	:	elevation angle (degree)
φ	:	Latitude of the earth station (degree)
f	:	frequency (GHz) in ku, ka, and, V bands, 14/12 , 30/20 , 50/40
R_e	:	effective radius of the earth (8500 km)

Step 1: Determine the rain height, h_R, as given by the ITU-R

Step 2: For $O \geq 5°$, compute the slant path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_S)}{\sin\theta} \text{ km} \tag{1}$$

For $\theta < 5^\circ$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left[\sin^2/\theta + \frac{2(h_R - hs)}{R_e}\right] + \sin\theta^{1/2}} \text{ km} \tag{2}$$

If $h_R - h_S$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and following steps are not needed.

Step 3: Calculate the horizontal projection, L_G, of the slant path length from:

$$L_G = L_G \cos\theta \text{ km} \tag{3}$$

Step 4: Obtain he rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If this longterm statistic cannot be obtained from local data source, an estimate can be obtained from the maps of the rain rate. If $R_{0.01}$ is equal to zero, then the predicted attenuation is zero for any time percentage and the following steps are not needed.

Step 5: Obtain specific attenuation, γ_R, using the frequency-dependent coefficients and the rainfall rate $R_{0.01,}$ obtained from *Step* 4 by using:

$$\gamma_R = k(R_{0.01})_a \text{ dB/km} \tag{4}$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\gamma_R}{f}} - 0.38(1 - e^{-2L_G})} \tag{5}$$

Step 7: Calculate the vertical adjustment factor $v_{0,01}$ for 0.01% of the time

$$\zeta = \tan^{-1}\left\{\frac{h_R - h_S}{L_G r_{0.01}}\right\} \text{ degrees} \tag{6}$$

For $\zeta > \theta$,

$$L_R = \frac{L_G r_{0.01}}{\cos\theta} \text{ km} \tag{7}$$

Else,

$$L_R = \frac{(h_R - h_S)}{\sin\theta} \text{ km} \tag{8}$$

If $|\varphi| < 36^0$, $\chi = 36 - |\varphi|$ degrees

$$X = 0 \text{ degrees}$$

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}(31(1 - e^{-\theta/(1+\chi)}))\frac{\sqrt{L_G\gamma_R}}{f^2} - 0.45} \tag{9}$$

Step 8:

$$\text{The effective path length} = L_E = L_R v_{0.01} \text{ km} \tag{10}$$

Step 9: The predicted attenuation for 0.01% of an average year is gotten from this:

$$A_{0.01} = \gamma_R L_E \ \text{ dB} \tag{11}$$

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range of 0.001%-5% is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36^0$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36^0$ and $\theta \geq 25^0$: $\beta = -0.005(|\varphi| - 36)$

Otherwise:

$$\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta, \tag{12}$$

$$A_p = A_{0.01}\left\{\frac{P}{0.01}\right\} - (0.655 + 0.033\ln(p) - 0.045\ln(A0.01) - \beta(1-p)\sin\theta. \tag{13}$$

This method provides an estimate of the long term statistics of attenuation due to rain. When measured statistics is compared with prediction, there is allowance given rather than large year to year variability in rainfall rate statistics (ITU-R [6]).

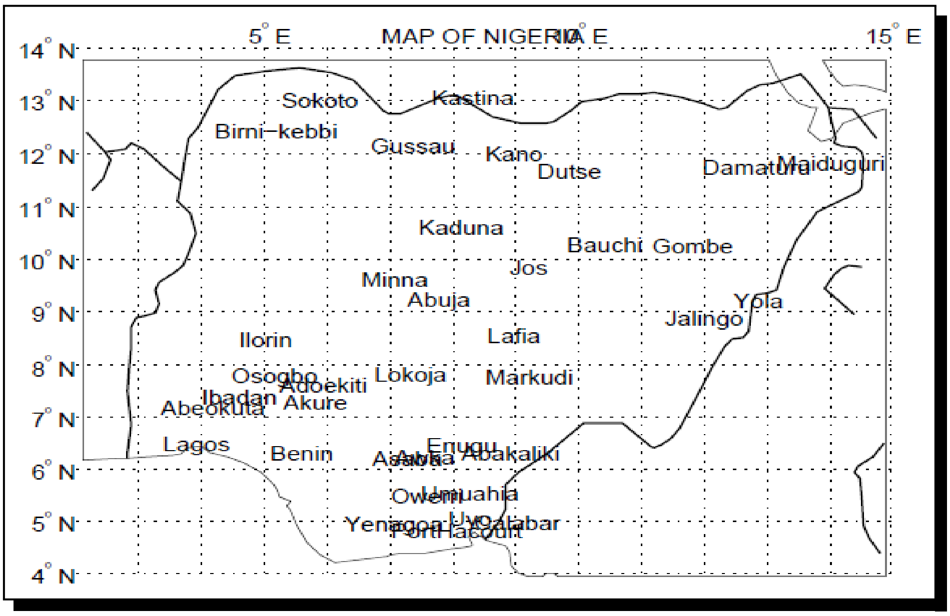

Figure 1. Map of Nigeria showing the Study Area

3. Result and Discussion

The results reveal that cross-polarization discrimination (XPD) become very poor as frequency (at Ku-band, Ka-band, V-band) increases especially at lower percentage of time (such as 0.001%, and 0.01%) unavailability. Hence XPD, at all frequencies is poorer in the southern part of Nigeria SE, SS and SW due to high rainfall rate.

There will be interference of signal all over Nigeria at 0.001% Ku Uplink because XPD was less than 30 dB ITU-R base line for Ku-band uplink transmissionexcept for Maiduguri and Damaturu with the value 30 dB.The results depicted in Figures 2-8 show that only Northern part of the country will experience no interference at 0.01% as XPD is over 30 dB ITU-R base line for Ku-band uplink transmission as shown in Figure 2.

In Figure 3, at 0.1% XPD is over 35 dB in most of the 37-station in Nigeria, this shows that there will be no interference in all the location for the country. Also, at 1% XPD is over 50 dB in most of the 37-station in Nigeria, this also confirmed that there will be no interference which is a good sign for radio communication industry as revealed in Figure 4.

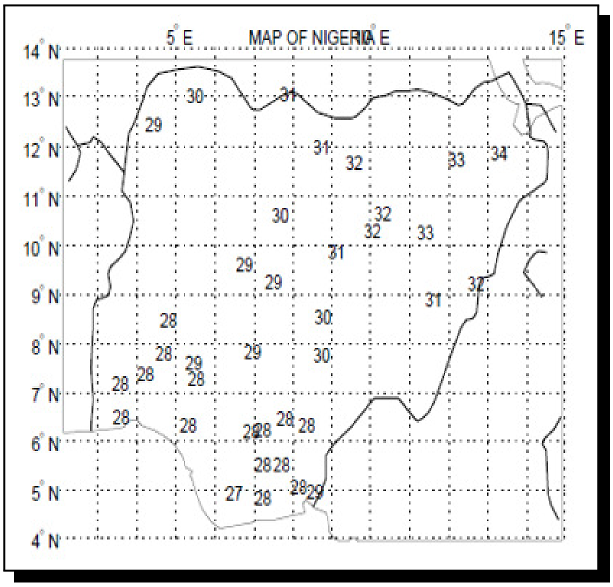

Figure 2. 0.01% 53 minutes outage in a year for Ku-band uplink

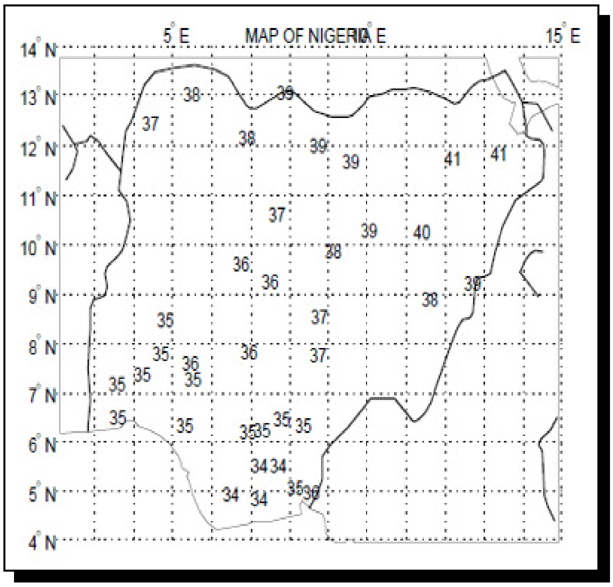

Figure 3. 0.01% 530 minutes outage in a year for Ku-band uplink

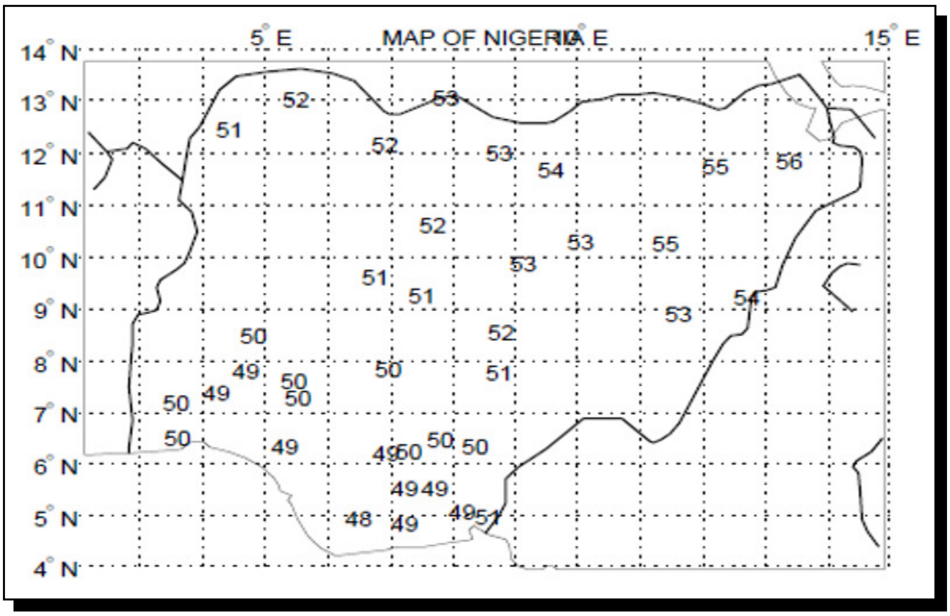

Figure 4. 1% 5300 minutes outage in a year for Ku-band uplink

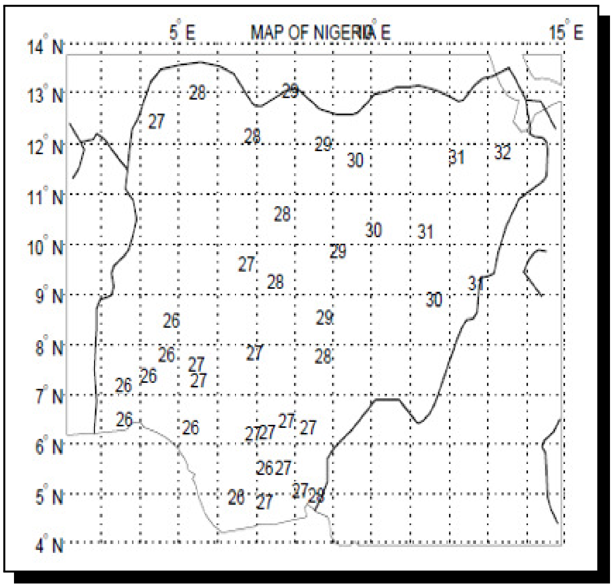

Figure 5. 0.001% 5.3 minutes outage in a year for Ku-band uplink

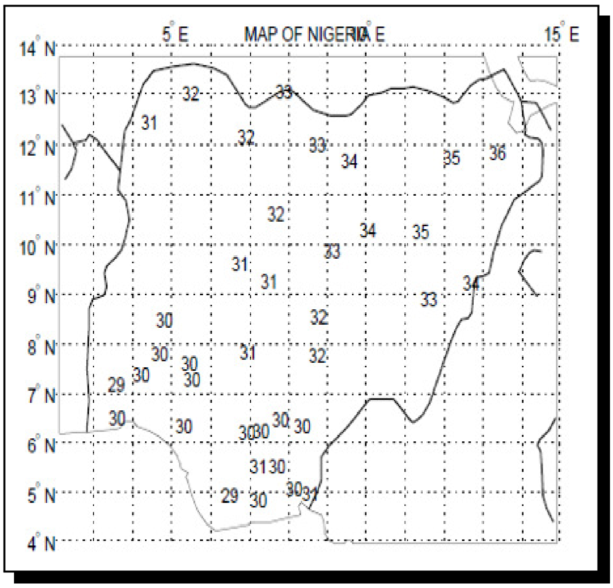

Figure 6. 0.01% 5.3 minutes outage in a year for Ku-band uplink

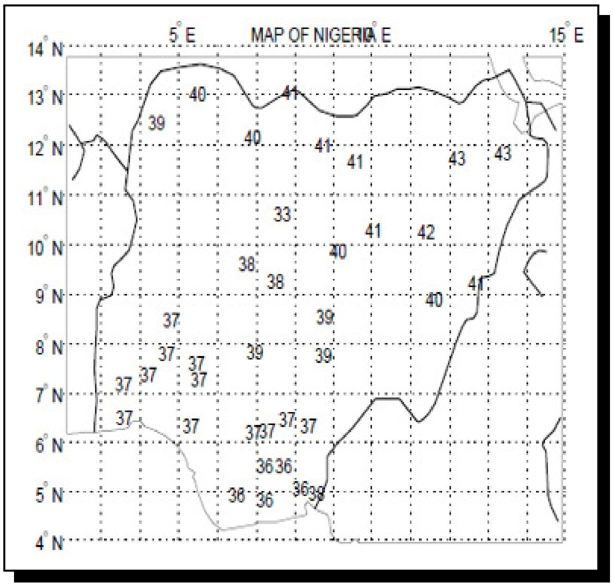

Figure 7. 0.1% 530 minutes outage in a year for Ku-band downlink

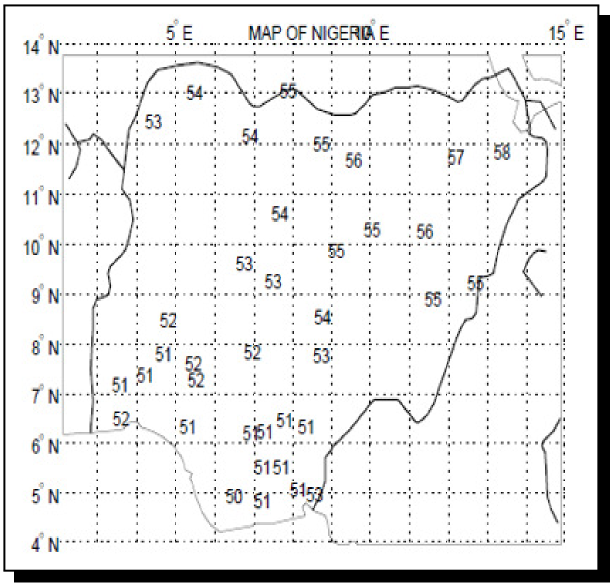

Figure 8. 1% 5300 minutes outage in a year for Ku-band downlink

However, the results observed in Figures 9-16 for Ka-band and V-band both uplink and downlink at 0.001% and 0.01% unavailability of time, interference will occur in all 37 locations in Nigeria, except for Maiduguri ka band (20GHz) downlink at 30dB, whereas, in Figure 9 at 0.1% Ka band uplink only Northern part of Nigeria (MB, NW and NE) has no interference, all southern part of Nigeria (SW, SE, and SS) will experience outage and interference. Also, Figure 13 depict at 0.1% V band uplink no interference for NE and NW and Jos in the MB. For uplink and downlink at 1%, XPD is over 40 dB for all 37-stations in Nigeria at Ka and V bands.

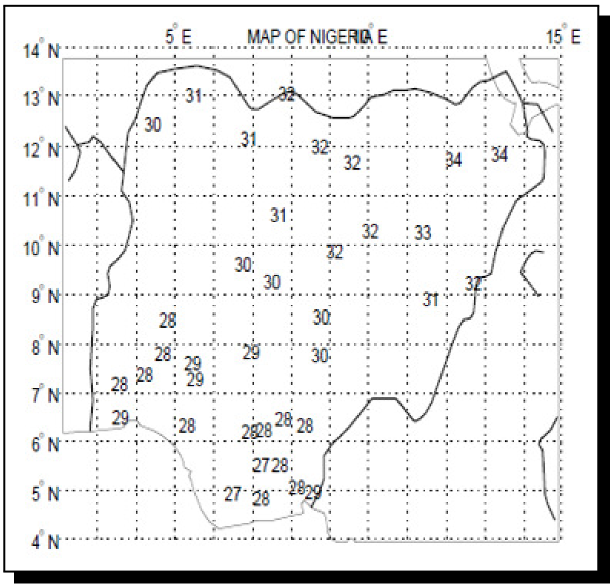

Figure 9. 0.1% 530 minutes outage in a year for Ku-band uplink

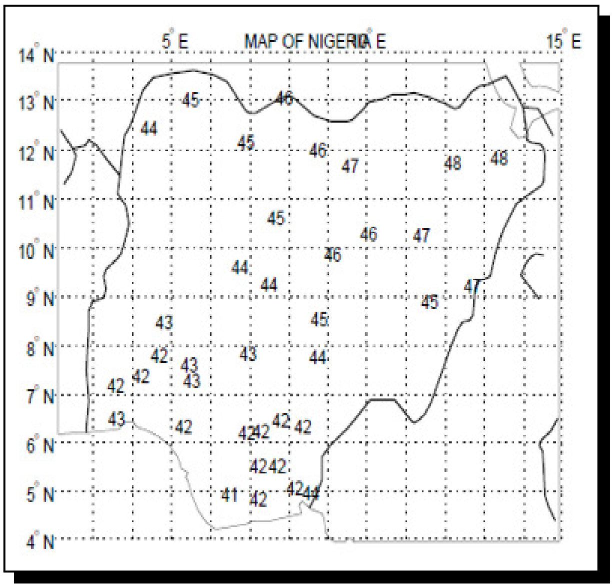

Figure 10. 1% 5300 minutes outage in a year for Ku-band uplink

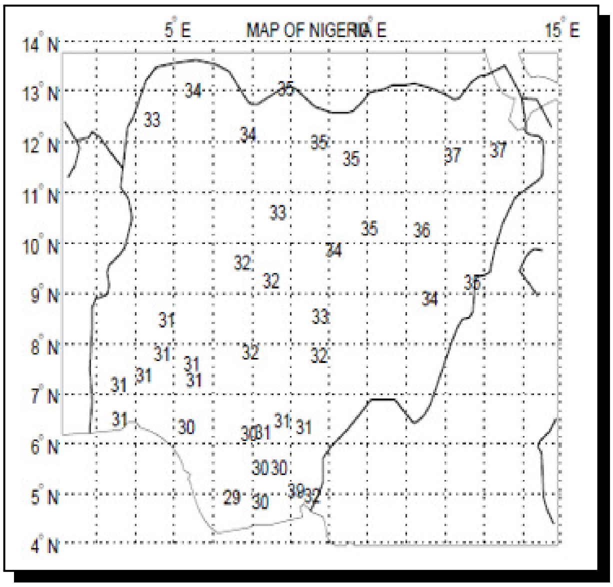

Figure 11. 0.1% 530 minutes outage in a year for Ku-band downlink

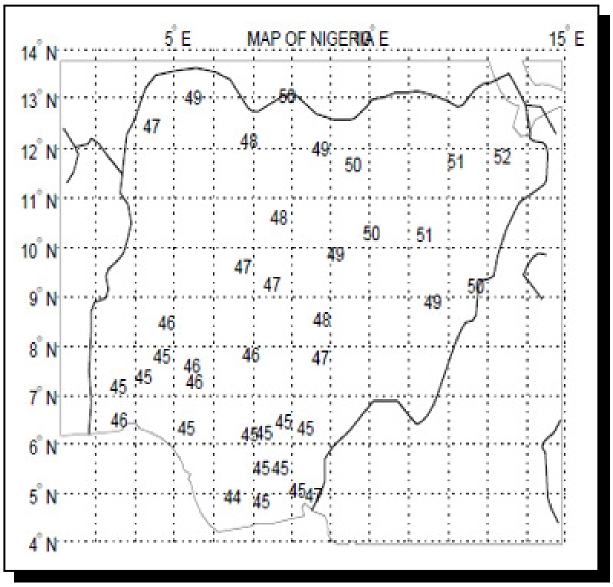

Figure 12. 1% 5300 minutes outage in a year for Ku-band downlink

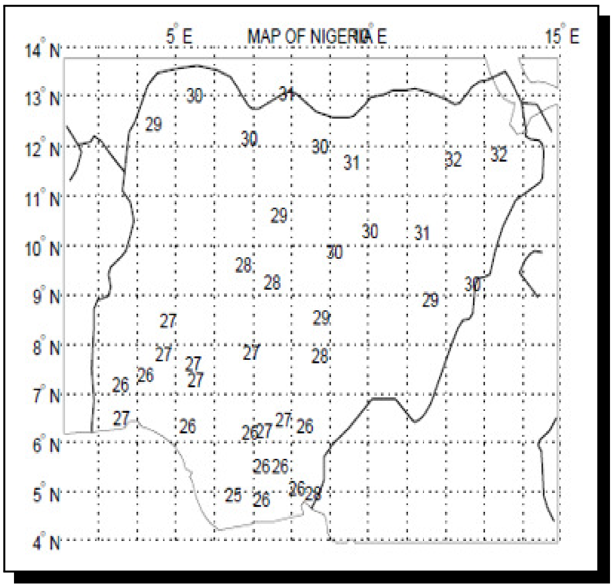

Figure 13. 0.1% 530 minutes outage in a year for V-band uplink

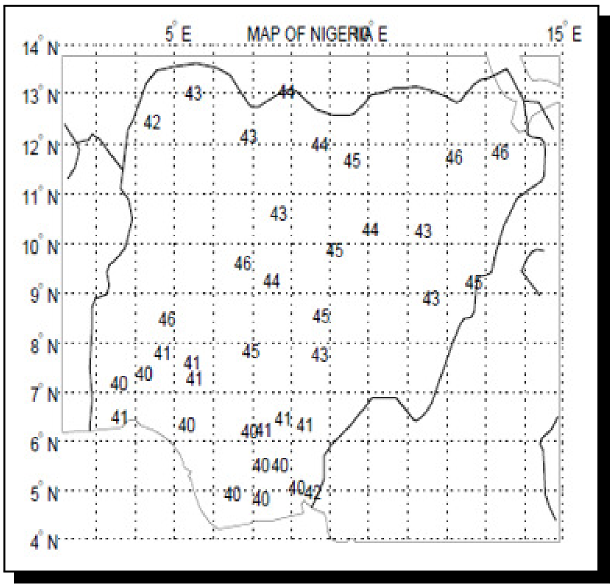

Figure 14. 1% 5300 minutes outage in a year for V-band uplink

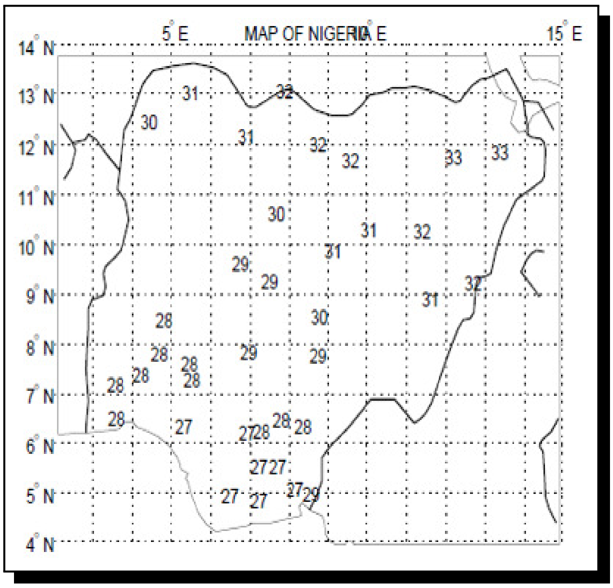

Figure 15. 0.1% 530 minutes outage in a year for V-band downlink

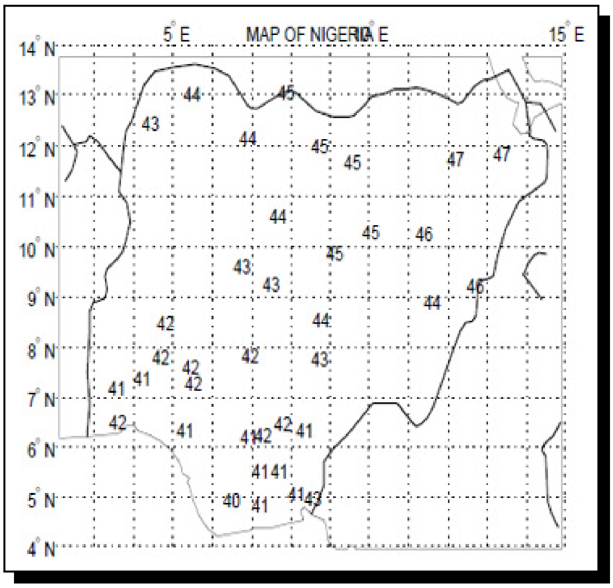

Figure 16. 1% 5300 minutes outage in a year for V-band downlink

4. Conclusion

The results reveal that cross-polarization discrimination (XPD) become very poor as frequency (at Ku, Ka and V-band) increase especially at lower percentage of time (such as 0.001%, and 0.01%) unavailability. Hence XPD, at all frequencies is poorer in the southern part of Nigeria SE, SS and SW due to high rainfall rate. The results also show that only Northern part of the country will experience no interference at 0.01% as XPD is over 30 dB ITU-R base line for

Ku-band transmission. However, for Ka-band and V-band at 0.001% and 0.01% unavailability of time, interference will occur in all 37 stations in Nigeria, but at 0.1% and 1% XPD is over 30 dB for all stations.

This study will help in the adequate planning and designing of satellite telecommunication expansion in all the six geopolitical zones in Nigeria. The result of this study will help in the adequate planning and designing of satellite telecommunication system expansion in all the six geopolitical zones in Nigeria and prevent interference between stations when using dual polarize signal to maximize bandwidth. The result will also enable the engineers in telecommunication industry in Nigeria to maximized bandwidth available at higher frequencies (at Ku, Ka, and V bands) in the microwave and millimeter wave region.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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