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Analysis and Prediction of Rain Attenuation: A Case Study of Maiduguri, Borno State, Nigeria

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Abstract: *This paper is aimed at determining the carrier-to-noise ratio, (C/N) during rain and clear sky, the Look angle, the Azimuth, and the rain attenuation analytically for a particular region over a location of (11.85N. 13.13E) to ascertain the impact of rainfall intensity and also the prediction of rain-induced attenuation. The parameters needed for these analyses were generated automatically through NIGCOMSAT 1R website. This result was achieved analytically using a formula, contour maps, and International Telecommunication Union (ITU-R) models. The result was verified to confirm their suitability and accuracy. These problems must be carefully examined for the accurate determination of the link budget.*

Key words: *Attenuation, Prediction, Satellite, Communication, Link Budget, Noise Ratio*

Introduction

The significance of communication in the development of human society is highly important. Access to information has thus become an important aspect of mass socio-economic development, as information underscores all aspects of development effort [1]. Africa remains the least continent in the world in terms of robust telecommunications infrastructure and systems to cover for its more than one billion people. Present infrastructure in the African environs is clearly insufficient, thus the need to develop national, sub-regional, and digital links with cross-border inter-connectivity as a means of closing the infrastructure deficiency. After due investigation and a request for proposals from various communications satellite companies, the Federal Government of Nigeria took the responsibility of signing a Communication Satellite contract with the China Great Wall Industry Corporation in December 2004. The high powered, Quad-band (Ku, Ka, C and L Band) geostationary satellite, with a service life span of 15 years, had 8 active transponders on the Ka-band, which were based on a feasibility field trial assessment of bandwidth demand projection for sub-Saharan Africa required to carry Africa's international voice and data traffic and the success of the ANIK F2 satellite with Ka-band [2]. Spatial and temporal distribution of rainfall is the main research problem for telecommunication scientists and engineers because of its impairing effects on the propagation of microwave signals at frequencies beyond 7 GHz. However, rain data received over longer-integration times tend to average out and under-estimate worst cases of rainfall intensity. It was reported that at Ku-band, the attenuation is not up to 1 dB during the clear sky, but can reach 10 dB during the raining condition. Signal attenuation levels are more than 20dB in the most tropical region of the world so resulting in network signal loss, particularly for time-critical services like banking, defence, telemedicine, and in the military. It is very expensive to completely mitigate this degradation [3]. Atmospheric effects play a vital role in the design of satellite-to-earth links operating at frequencies above 10GHz. Raindrops absorb and scatter radio waves, causing signal attenuation and decrease system availability and reliability. The harshness of rain impairment rises with frequency and changes with regional locations. Therefore, the incidence of rainfall on radio links becomes more important for frequencies as low as about 7GHz especially in tropical and equatorial climates, where extreme rainfall events are common. Rain-rate and rain attenuation maps for the country of Nigeria were established using the models mainly designed for tropical zones and also a model for the estimation of point rain rate, while the ITU model is used for rain attenuation prediction method [4]. There is a need for reliable rainfall rate data for planning and designing of the satellite communications system, management of water resources and to assess the effect of climate change. Rain gauge measurement networks are not as dense or evenly spaced in Nigeria as in the other developed countries like the US and Japan; thus satellite observation of rainfall networks may be the best solution for adequate temporal and spatial coverage of rainfall [5].

Satellite communication allows two or more earth stations to communicate with each other through a radio relay system. The radio signals while being transmitted through the atmosphere, during rain events, are mitigated by absorption and scattering through the transmission medium. However, the troposphere has a lot of water vapor molecules, carbon monoxide molecules, oxygen molecules, and various aerosols such as snow, fog, and rain; and all these affect radio signals, leading to continual absorption, reflection, and scattering, which causes energy reduction (and attenuation). Rain attenuation can be defined as the product of "specific attenuation" in dB/km and the "effective propagation path length" in km. The ratio of the attenuation due to rainfall to the specific attenuation is referred to as the point rain rate while the product of the "path reduction factor" and the "physical path length". The concept of effective path length is a method to average out the spatial inhomogeneity that is inherent in rain rate, and accordingly, the specific attenuation. Due to spatial inhomogeneity in rain rate which largely fluctuates with rainfall intensity, changes in path length reduction factor can be said as a function of rain rate or its corresponding time exceedances. Attenuation can, then, be derived from direct measurements or can be predicted from the knowledge of long-term rain rate [6].

Nigcomsat 1R

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Satellite Name: Nigcomsat 1R
Status: active
Position: 42° E (42.5° E)
NORAD: 38014
Cospar number: 2011-077A
Operator: NASRDA
Launch date: 19-Dec-2011
Launch site: Xichang Satellite Launch Center
Launch vehicle: Long March CZ-3B/E
Launch mass (kg): 5150
Dry mass (kg):
Manufacturer: China Aerospace Science and Technology Corporation (CASC)
Model (bus): DFH-4 Bus
Orbit: GEO
Expected lifetime: 15 yrs.

Call sign:
Beacon(s):
Details:
4 C, 14 Ku, 8 Ka and 2 L-band transponders to provide the most optimal and cost effective voice, data, video, internet and application service/solutions
Charts: list

Fig 1: NIGCOMSAT 1R Parameter.

Reception details	
42°E — Nigcomsat 1R	
Ku-band ECOWAS 1 beam	
Distance to satellite:	36796.8km
Location:	11.85°N 13.13°E
Elevation angle:	53.9°
LNB Tilt (skew):	66.5°
True azimuth:	110.4°
Next Sun azimuth match at:	05:31:39 (GMT) 13:31:39 (PC time)

Fig 2: Ku-band ECOWAS 1 Beam Parameter.

Reception details	
42°E — Nigcomsat 1R	
C-band ECOWAS 1 beam	
Distance to satellite:	36796.8km
Location:	11.83°N 13.13°E
Elevation angle:	53.9°
LNB Tilt (skew):	66.5°
True azimuth:	110.4°
Next Sun azimuth match at:	05:31:19 (GMT)
	13:31:19 (PC time)

Fig 3: NIGCOMSAT 1R Parameter for C-Band ECOWAS 1 Beam

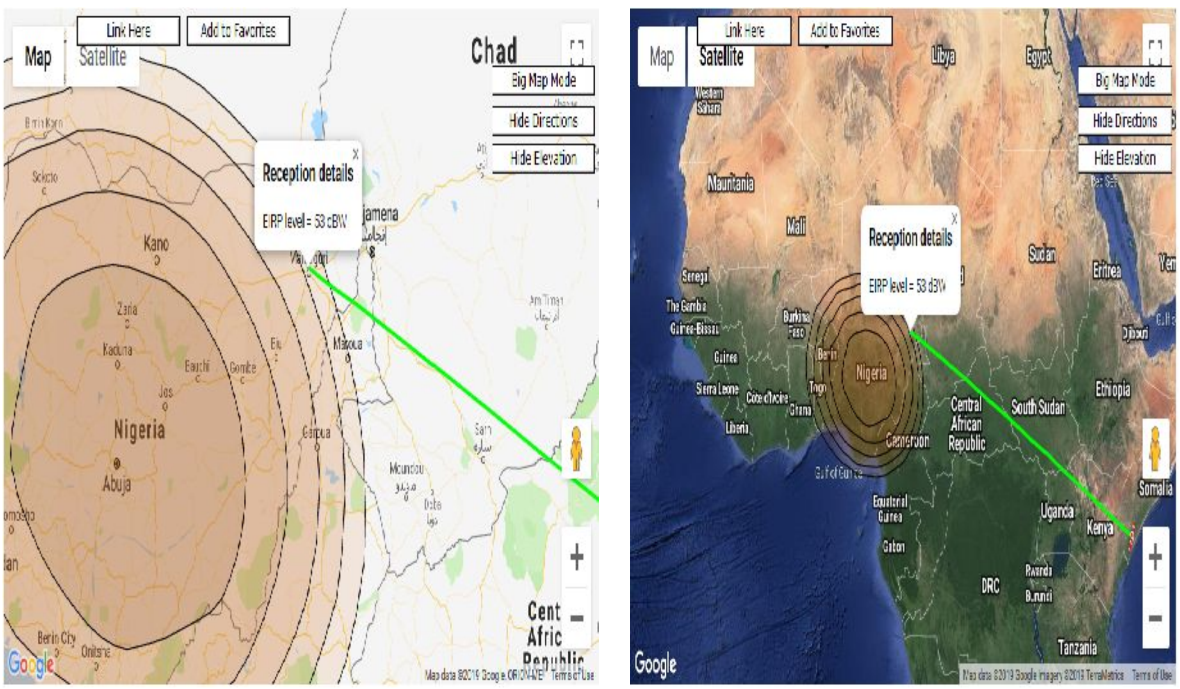


Fig 4: Automatic Parameter Generation On Map Showing Maiduguri and its Environs.

Fig 5: Automatic Parameter Generation On Map Showing Maiduguri and its Environs.

Determining The Look Angle and Azimuth Analytically

Parameter from NIGCOMSAT 1R

i. $ES \rightarrow 13.13°E,\ \ 11.9°N$

ii. $S \rightarrow 42°E,\ \ 0°N$

Resolving Using the Formula Method

$$cos(\gamma) = cos(L_E)cos(I_{S\_}I_E) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$= cos(11.9)cos(42\_13.13) = 0.857$$

$$\gamma = 31.03$$

$$r_s = 43174.94km, \quad r_e = 6378.14km$$

Determining The Look Angle and Azimuth Analytically

$$cos(EL) = \frac{sin(\gamma)}{\left[1+\left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)cos(\gamma)\right]^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$= \frac{sin(31.03)}{\left[1+\left(\frac{6378.14}{43174.94}\right)^2-2\left(\frac{6378.14}{43174.94}\right)cos(31.03)\right]^{\frac{1}{2}}}$$

$EL = 53.99°$

$$= \tan^{-1}\left[\frac{\tan(42-13.13)}{\sin 11.9}\right] = 69.494$$

$AZ = 180 - \alpha \; = \; 180 - 69.494 = 110.5$

$AZ = 110.5°$

Obtaining C/N During Clear Sky

Taken F = 12GHz for down link Ku band

$EIRP = P_t, \; G_t, \; = 53dBw, \; P_r = ?, \; G_t, = ?, \; N = ?, \; C/N = ?,$

$Recal \; P_r = P_t + G_t + \; G_r - \; L_p$ ....(3)

Looking for the antenna gain

Using $\eta = 60\%, \quad D = 2m$

$but \; \lambda = \frac{C}{F}$ ....,(4)

$$= \frac{3\times10^8}{12\times10^9} = 0.025$$

$G_r = \eta\left(\frac{\pi D}{\lambda}\right)$ ....(5)

$$= 0.6 \times \left(\frac{\pi \times 2}{0.025}\right) = 45.8db$$

Looking for Free Space Loss

$L_s = 32.45 + 20log36796.8 + 20log12000MHz = 205.35dB$

Clear path loss= $2dB$

$\therefore total \; loss = 205 + 2 = 207.35dB$

$hence,\ P_r = 53 + 45.8 - 207.35 = -108.5dB$

$but\ N = BKT$ ....(6)

Equally

$T_S = T_{in} + T_R$ ....(7)

$T_{in} = 270\left(1 - 10^{-\frac{2}{10}}\right) = 100k$

$T_S = 100 + 100 = 200k$

$N = 1.3 \times 10^{-23} \times 200 \times 8 \times 10^{8} = 2.208 \times 10^{-14} = -136.56dBw$

$C/N = P_r - N$ ....(8)

$= -108.5 - (-136.56dB) = 28.1dB$

G/T Ratio of Earth Station

The ratio of the earth station G/T

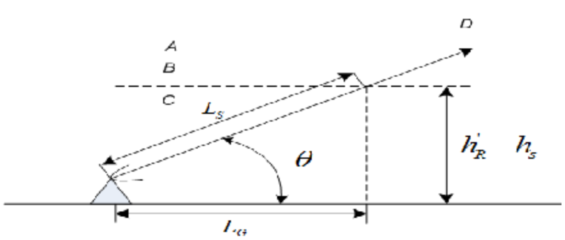
$G/T = \frac{G_r}{T_s}$ … … … … … … … … … … … … … … … … … . . (9)

$= \frac{45.8}{28.1} = 2dB$

Hence $C/N > G/T$

Determining Rain Attenuation

$A = \gamma_R L_{eff}$ ....(10)



Taken

$h_r = 5,\quad h_s = 0,\quad = 11.9°$

$\therefore L_s = \frac{h_r - h_s}{\sin\theta}$ ....(11)

$$\therefore \frac{5-0}{\sin 53.9} = 6.188$$

$\therefore L_G = L_s \cos\theta$ ....(12)

$= 6.188 \times \cos 53.9 = 3.646$

Rain rate contour map $R_{0.01} = 85$

$\gamma_{R=} K(R_{0.01})^{\alpha}\text{Db}$ ....(13)

$\gamma_{R=} 0.0168(85)^{1.217} = 3.745 dB/km$

Table 1: Table of Coefficient [4].

F (GHz)	k_H	k_V	$\propto_H$	$\propto_V$
4	0.00065	0.00059	1.121	1.075
6	0.00175	0.00155	1.308	1.265
8	0.00454	0.00395	1.327	1.310
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.200
20	0.0751	0.0691	1.099	1.065
30	0.187	0.167	1.021	1.000
40	0.350	0.310	0.939	0.929
50	0.536	0.479	0.873	0.868

Table 2. Local climatological parameters of the stations in Nigeria [4].

Station	Longitude (°N)	Latitude (°E)	Average annual accumulation (mm/year)
Akure	5.18	7.17	1485.57
Ikeja	3.2	6.3	1425.207
Calabar	8.17	4.58	2864.907
Minna	6.33	9.36	1196.751
Kano	8.3	11.58	924.850
Makurdi	8.53	7.32	1337.371
Sokoto	5.13	13.04	567.206
Maiduguri	13.08	11.51	648.455
Dikwa	14.52	12.08	657.433
Adamawa	12.3	9.10	1012.398
Ile Ife	5	7.5	1215.27
Ilorin	4.5	8.5	1232.775
Port Harcourt	7	4.2	2803.104
Warri	5.44	5.29	2617.503
Enugu	7.27	6.25	1876.301
Abuja	9.25	7.1	1777.538
Saki	3.23	8.39	1097.968
Jos	8.5	9.5	1186.89
Gombe	11.11	10.16	746.805
Bauchi	9.5	10.18	849.397
Kaduna	7.26	10.33	1103.464
Zaria	7.41	11.04	801.879
Borno	12.45	11.59	574.488
Gusau	6.4	12.09	650.288
Nguru	10.25	12.59	451.586
Katsina	7.35	13	556.336

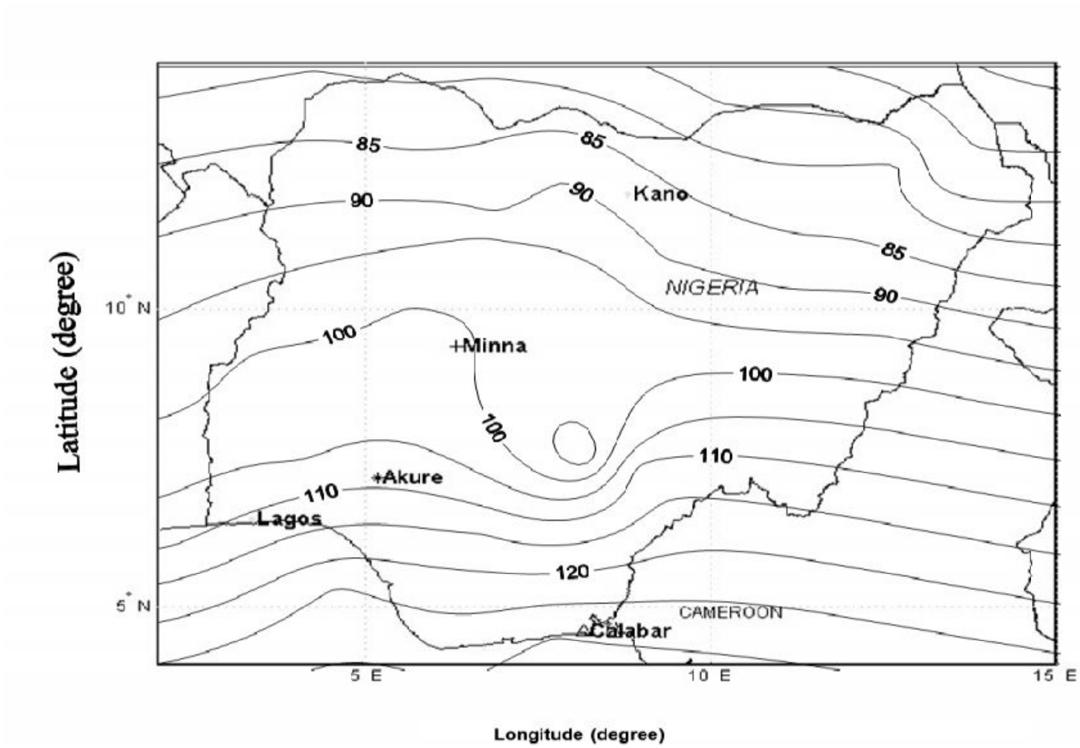


Figure 6. Rain Rate (Mm/H) Contour Maps For 0.01% Of Time In Nigeria [4].

The horizontal reduction factor $r_{0.01}$ for 0.01%

$$r_{0.01} = \frac{1}{1+0.78\left(\sqrt{\frac{L_G\gamma}{f}}\right)-0.38\left(1-e^{(-2\times L_G)}\right)} \quad \text{............(14)}$$

$$r_{0.01} = \frac{1}{1+0.78\left(\sqrt{\frac{3.646\times 3.745}{12}}\right)-0.38(1-e^{(-2\times 3.646)})}$$

$$r_{0.01} = 0.688$$

Calculating The Vertical Adjustment Factor

$$\therefore \xi = \tan^{-1}\left(\frac{h_r-h_s}{L_G r_{0.01}}\right) \quad \text{......................................(16)}$$

$$= \tan^{-1}\left(\frac{5-0}{3.646\times 0.6885}\right) = 63.34 \text{ deg}$$

$\xi = 63.34, \qquad \xi > \theta$, satisfied for the condition. therefore

$$L_R = \frac{L_G r_{0.01}}{\cos\theta} \quad \text{...(17)}$$

$$\frac{3.646 \times 0.6885}{\cos 53.9} = 4.26$$

Considering the latitude of Maiduguri Borno state. Nigeria (11.9°)

$\therefore$ *the latitute of Maiduguri* < 36

$$\chi = \begin{cases} 0, & \phi \geq 36^\circ \\ 36 - |\phi|, & \phi < 36 \end{cases}$$

$hence, \ X = 36 - 11.9 = 24.1$

The Vertical Adjustment Factor

$$V_{0.01} = \frac{1}{1 + (\sqrt{\sin\theta})\left[31\left(1 - e^{-\theta(1 \div x)}\right) \times \left(\sqrt{\frac{L_R \gamma}{f^2}}\right) - 0.45\right]} \quad \text{..............(18)}$$

$$V_{0.01} = \frac{1}{1 + (\sqrt{\sin 53.9})\left[31\left(1 - e^{\frac{-53.9}{1+24.1}}\right) \times \left(\sqrt{\frac{4.26 \times 3.745}{12^2}}\right) - 0.45\right]} \quad \text{.........(19)}$$

$V_{0.01} = 0.114$

Calculating Attenuation

Effective path loss

$$L_E = L_R \times V_{0.01} \quad \text{...(20)}$$

$= 4.26 \times 0.114 = 0.48km$

The Predicted Attenuation

$$A_{0.01} = \gamma L_E \quad \text{..(21)}$$

$= 0.48 \times 3.745 = 1.82dB$

Calculating CNR During Rain

$$T_S = T_{in} + T_R \quad \text{...}(22)$$

$$T_{in} = 270\left(1 - 10^{-\frac{A}{10}}\right),\ A = 2 + 1.82 = 3.82$$

$$T_{in} = 270\left(1 - 10^{-\frac{3.82}{10}}\right) = 158k$$

$$T_S = 100 + 100 = 257k$$

$$N = 1.3 \times 10^{-23} \times 258 \times 8 \times 10^{8} = 2.68 \times 10^{-12} = -115dBw$$

$$C/N = P_r - N \quad \text{...}(23)$$

$$= -108.5 - (-1156dB) = 7.21dB$$

Ratio of The Earth Station $^G/_T$

$$^G/_T = \frac{G_r}{T_s} = \frac{45.8}{24.1} = 1.9dB$$

Hence $C/N > {^G/_T}$

Result

The result summary.

Name	Result
Elevation Angle Analytically	53.99^0
Azimuth Analytically	110.5^0
C/N During Clear Sky	28.1Db
Predicted Rain Attenuation	1.82dB
CNR During Rain	**7.21**dB

Conclusion

Conclusively the formulas ware proven reliable as can be seen during determining the elevation angle (EL) which is 53.99^0 compared to 53.9^0 which was generated automatically from NIGCOMSAT 1R website. However careful measures must be taken to ascertain the accuracy of the result. The result obtained will be very helpful in the satellite link budget and design.

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