Investigation of the Applicability of Garcia and ITU-R Models to Rainfall on Satellite Communication Link in Nigeria

Adeyemo. Z.K., Akande. D.O. and Ojo. F.K.

Abstract— This paper presents the investigation into the effect of rain on satellite communication link in Nigeria at a frequency of 30 GHz, using six cities in each geographical zone of the country. The annual rainfalls of the cities spanning a period of three years were collected from the Nigerian Meteorological Centre for proper analysis. The ITU-R rain attenuation model and the Garcia Model were considered among several models in existence. The average rain rate value was computed and substituted into the rain attenuation prediction models under study. The result obtained, indicates that value of attenuation increases as the altitude decreases. Also, the analysis of the results shows that the Garcia model is more applicable in Nigeria using both horizontal and vertical polarizations.

Index Terms— Rain rate, attenuation, polarization, satellite.

1 Introduction

One of the major problems facing the successful propagation of communication between the transmitter and the receiver along a communication path is attenuation. Rain plays a significant role in the undesired absorption of microwave, milimetre and centimetre wave propagation in the lower atmosphere. Beside rain, other major contributors are water vapour, liquid water clouds and fog [1]. Rain rate distribution is one of the most important factors for calculating rainfall attenuation at a specific location [2]. Rain attenuation becomes considerable at frequencies above 10 GHz [3]. The effect of rainfall is more severe in tropical regions which are characterized by heavy rainfall intensity and presence of large raindrops [3]. Rain attenuation decreases the intensity of signals sent through the satellite as rain has the ability of scattering and absorbing signal waves. To achieve effective communication, there is a need to study the effect of this natural phenomenon on the radio propagation path above 10 GHz, using the various rain attenuation statistical models. A lot of research work has been carried out in this area over the years globally [1],[4],[5],[6],[7] and [8]. In Nigeria, more research needs to be carried out to ensure reliable signal and appropriate model [3],[9] and [10] to mention but few. It is therefore, pertinent to investigate the effect of rain since Nigeria has successfully launched its satellite into the earth orbit. This research work focus on the NIGCOMSAT 1R propagation link and two prediction models that suit the tropical climate to which Nigeria belong.

2 Material and Method

The technical data such as position, elevation, latitude, longitude and altitudes at six different locations: Ikeja, Kano, Lokoja, Enugu, Maiduguri and Port-Harcourt from each of the geographical zone in Nigeria were analysed using the ITU-R and Garcia models to determine the appropriate model for satellite communication in Nigeria..

2.1 Rain rate Prediction models

2.2 ITU-R models

To estimate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz the following steps have to be carried out using [11].

Step 1: Determination of the effective rain height, h_R, for the latitude of the station φ:

$$h_R = 5 - 0.075(\varphi - 23) \ for \ \varphi > 23^{\circ} \text{ for the northern hemisphere} \quad (1)$$

Step 2: For $\theta \geq 5^{\circ}$ compute the slant-path length, L_s, below the rain height from:

$$L_s = (h_R - h_s)/\sin\theta \quad (2)$$

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

$$L_G = L_s \cos\theta \quad (3)$$

Step 4: Obtain the rain intensity, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If that information cannot be obtained from local data sources, an estimate can be obtained from the map of rain climates given in [12]. An alternative method is by applying the Chebil model, which makes use of long-term mean annual accumulation, M, at the location under study [13] and is given by

$$R_{0.01} = \alpha M^{\beta} \quad (4)$$

Where α and β are regression coefficients. This model was shown to provide good approximation of the measured data. The regression coefficients are defined as:

$$\propto = 12.2903 \text{ and } \beta = 0.2973$$

Step 5: Calculate the reduction factor, $R_{0.01}$, for 0.01% of the time for $R_{0.01} \leq 100\ mm/h$:

$$R_{0.01} = 1/(1 + L_G/L_o) \quad (5)$$

$$\text{where } L_o = 35\exp(-0.015)R_{0.01} \quad (6)$$

Step 6: Obtain the specific attenuation, γ_R, using he frequency dependent coefficients given in [12] and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k(R_{0.01})^{\propto} \quad \text{(dB/km)} \quad (7)$$

Step 7: The estimated attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R L_s R_{0.01} \quad \text{(dB)} \quad (8)$$

Step 8: The estimated attenuation to be exceeded for other percentage of an average year, in the range 0.001% to 1%, is determined from the attenuation to be exceeded for 0.01% for an average year by using:

$$A_n = A_{0.01}\ 0.12p^{-(0.546 + 0.043\log p)} \quad \text{(dB)} \quad (9)$$

2.3 Garcia Model

Rain attenuation for satellite link as obtained from [14] and [15] as;

$$A_n = kR_n^{\propto} L_s/(a + (L_s(bR + cL_s + d)/e)) \quad \text{(dB)} \quad (10)$$

- *Dr. Z.K Adeyemo is a senior lecturer in the department of electronic and electrical engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. E-mail:zkadeyemo@yahoo.com.*
- *D.O Akande is a lecturer in the department of electronic and electrical engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. E-mail:akandedamilare@yahoo.com.*
- *F.K Ojo is a lecturer in the department of electronic and electrical engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. E-mail:festusoluseye@yahoo.com*

where L_s is the equivalent path length, in km, given by,

$$h_R = 4 - 0.075(\varphi - 36) \quad \text{(km)} \quad \varphi \geq 36^{\circ} \quad (11)$$

The coefficients a, b, c and d are constants depending on the geographical area. Coefficient e is only a scaling factor. Taking e = 10^2, the "worldwide" coefficients are: a=0.7, b=18.35, c=-16.51, d=500.

3 Simulation Parameters

The simulation of the two prediction models were carried out using MATLAB software package. The parameter of the satellite under study at a frequency of 30 GHz is as shown in Table 1.

Table 1: Parameter of satellite under study

Satellite	Position	Elevation
NIGCOMSAT-2	42.5^0 E	5^0 , 55^0

The parameters of the cities used study is presented in Table 2.

Table 2: Parameters of cities under study

Cities	Latitude	Longitude	Altitude (km)
Enugu	$06^0$28′N	07^0 33′E	137.3
Maiduguri	$11^0$51′N	13^0 05′E	348.0
Port Harcourt	$05^0$01′N	06^0 57′E	85.0
Kano	$12^0$05′N	$08^0$32′E	475.8
Ikeja	$06^0$35′N	$03^0$20′E	128.55
Lokoja	07^0 48′N	$06^0$44′E	62.4

4 Result and Discussion

Rain attenuation increases with increasing frequency, and with decreasing elevation angle. Nigeria being in the tropic region, rain at times is from convective rain-cells, with relatively small diameters often resulting in 'heavy' down pours for short periods. From the study it was observed that Garcia model is more sensitive to elevation. Comparing the probability of two models, it can be concluded that the Garcia model for both vertical and horizontal polarisation revealed Lokoja to have the greatest attenuation from Figures 1 and 2 the greatest attenuation being the area with the lowest altitude with Kano having the lowest attenuation value, while the ITU-R model in Figures 3 and 4 for both vertical and horizontal revealed Maiduguri to be the city with the highest attenuation value, while Port Harcourt has the lowest attenuation value; although Port Harcourt does not have the lowest altitude value and Maiduguri is not the area with the highest altitude. This clearly supports the fact that Garcia model is more sensitive to elevation and altitude of the location of satellite.

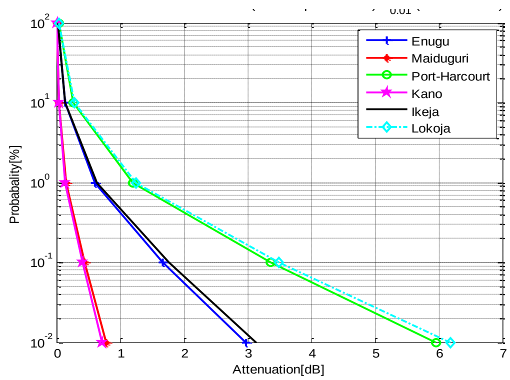

Fig. 1. Probability against attenuationfor Gracia model (vertical polarization)

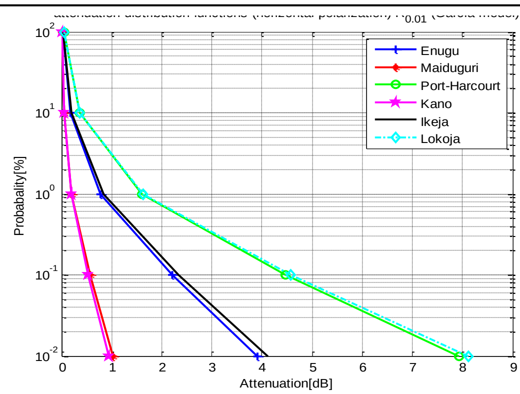

Fig. 2. Probability against attenuationfor Gracia model (horizontal polarization)

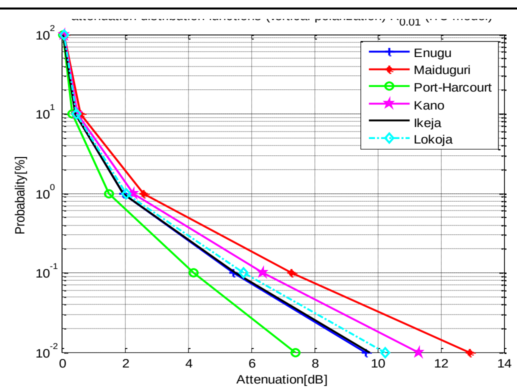

Fig. 3. Probability against attenuationfor ITU-R model (vertical polarization)

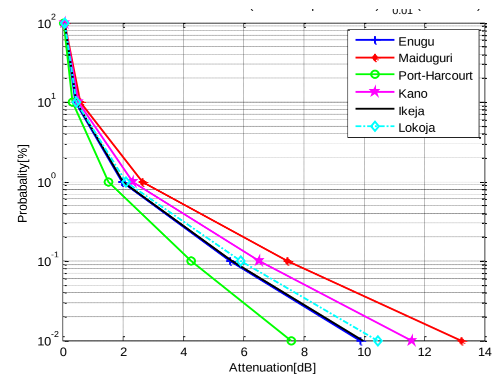

Fig. 4. Probability against attenuationfor ITU-R model (horizontal polarization)

The exceedence curves for rain rate and attenuation showed clear breakpoints; implying changes in the rain structure and hence attenuation. From Figures 5 to 10 the breaking point is close to 0.1% after which the attenuation decreases as the percentage of time increases. This is because breakpoint is more evident if the time rate is short. Looking through Figures 5 to 10, it was observed that ITU-R produces a higher value of attenuation than Garcia model .For instance, in Figure 5, Enugu at 0.1% of time ITU-R has an attenuation of 4.2 dB while Garcia model has an attenuation value of 0.8 dB. This still support the fact that Garcia model is better adopted in Nigeria. Hence ITU-R produces a poor attenuation and exceedence prediction.

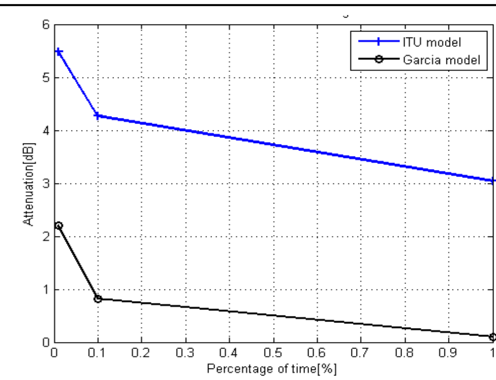

Fig. 5. Attenuation against percentage of time for Enugu

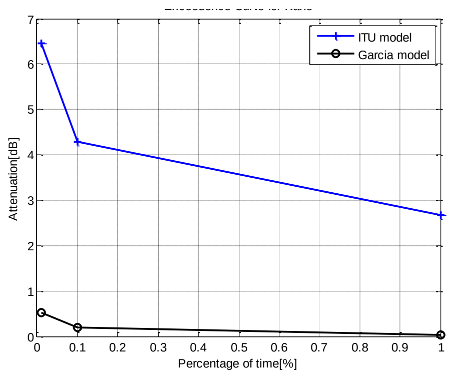

Fig. 6. Attenuation against percentage of time for Kano

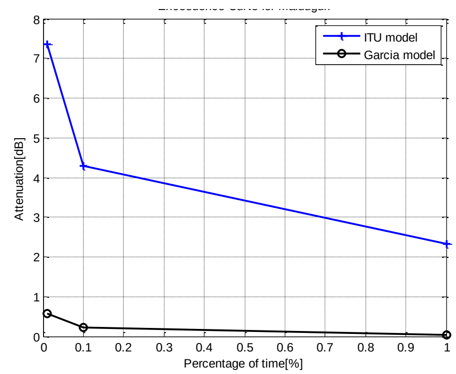

Fig. 9. Attenuation against percentage of time for Maiduguri

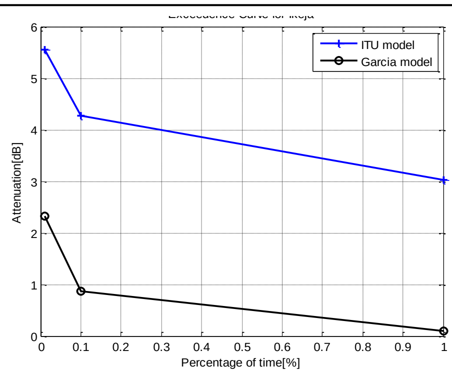

Fig. 7. Attenuation against percentage of time for Ikeja

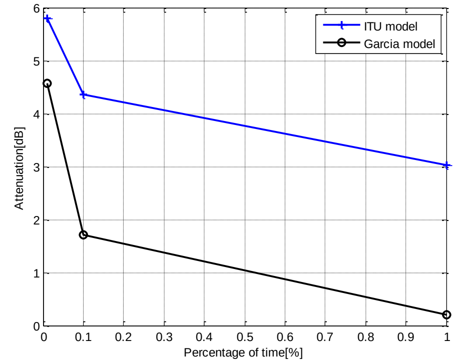

Fig. 10. Attenuation against percentage of time for Lokoja

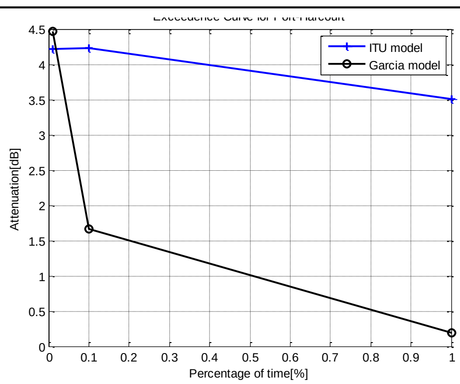

Fig. 8. Attenuation against percentage of time for Port-Harcourt

5 CONCLUSION

In this paper, the effect of rain on satellite communication link in Nigeria using Garcia and ITU-R models has been investigated using Nigeria data. Evaluation was carried out using the probability and attenuation in both horizontal and vertical polarisation. The result obtained from the analysis showed that attenuation increases as angle and altitude decreases. Moreover, the analysis of the results also shows that the Garcia model is more applicable to Nigeria data, thus, recommend also for use in Nigeria. It can be seen that Kano with the highest altitude has the lowest attenuation value while Lokoja with the lowest altitude has the highest attenuation the Garcia model for both vertical and horizontal polarization. Also, Port Harcourt and Maiduguri have the lowest and highest attenuation value respectively for the ITU-R model.

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