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EVALUATION OF RAINFALL RATES AND RAIN-INDUCED SIGNAL ATTENUATION FOR SATELLITE COMMUNICATION IN THE SOUTH-SOUTH REGION OF NIGERIA

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Abstract

Rain fade causes signal attenuation which can relatively results in signal quality performance degradation, increased pathloss and coverage area reduction in satellite communication networks, most especially in the tropics and at higher operational frequencies above 10GHz. Analysis of rain attenuation provides useful insight for satellite communication engineers for efficient network planning and design within the region of study. Hence this paper presents three-year analysis of signal-induced attenuation in the South-South States of Nigeria for the cities of Port-Harcourt, Uyo, Calabar and Eket, whose terrain characteristics could be generalized to represent urban, sub-urban and rural terrains in Nigeria. The International Telecommunications Union Radio-wave propagation (ITU-R P618-13) model was used to estimate the long-term rain attenuation at 10GHz, 20GHz and 30GHz for satellite communication applications. Results obtained at 10GHz, 20GHz and 30GHz operational frequencies show that at high frequency, rain fade can cause signal attenuation levels in the south-south region of Nigeria. In all, Calabar recorded the highest rain rate and corresponding highest attenuation level of 96.13dB at 30GHz compared to 50.29dB at 20GHz for the period under review.

1.0 INTRODUCTION

Satellite communication systems have become an essential part of the worlds' communication infrastructure, serving billions of people with telephone, data, and video services. Satellite systems remain the most cost-effective means of connecting regions under emergency conditions [1]. Satellite network has the advantage of wide coverage compared to terrestrial wireless network [2][3][4]. Some factors that affect satellite communication link include limited elevation angle [5][6], pathloss between the communication points [7], energy level [8] frequency of communication and rain attenuation. Deplorably, satellite signal propagation above 10GHz experience significant attenuation level due to rain absorption and scattering of the energy density of the incident electromagnetic wave by individual drops of rain [9][10]. Among the atmospheric conditions, rainfall significantly affects signal strength operating above 10GHz. The level of signal attenuation due to rain depends on the rate of rainfall, often measured in terms of millimeters per hour (mm/hr). Rain induced attenuation at higher frequencies is generally considered as function of frequency of signal

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propagation, rain fall intensity as well as rain drop size and temperature distribution [11].

Thus, it is important to note and consider transmit power level in terms of Effective Isotropic Radiated Power [12][13] when designing a satellite communication network in order to avoid propagation losses caused by rain attenuation and ensure strong signal strength for improved communication experience. It is also important to consider impact of rain induced attenuation when planning both microwave satellite and terrestrial line-of-sight links [14][15][16] and provide adequate compensation to avoid signal degradation. Methods for the prediction of rain attenuation on microwave paths have been grouped into two classes: the empirical method which is based on measurement databases from stations in different climatic zones within a given region and the physical method which makes an attempt to reproduce the physical behaviour involved in the attenuation process. When a physical approach is used, not all the input parameters needed for the analysis are always available. Section two of this article presents related work on this research and section three describes the research methodology. Section four presents result and discussion. The research article is concluded in section five.

2.0 RELATED WORK

Several efforts have been made by many researchers and authors to evaluate rain rate and rain attenuation and degradation within and outside Nigeria. Some Tropical Rainfall Rate Characteristics and rain fade calculation technique are discussed [17]. Review of current and future satellite communication technologies and applications, successfully quantified the various influences of rain attenuation on received power at Ka-band. Other studies such as [18][19] also estimated rain attenuation of Earth-to-Satellite link. The Rice-Holmberg (R-H) and ITU models were used for rain rate and rain attenuation estimation respectively. Rain attenuation prediction model, rainfall rate estimation and rain attenuation estimation were all analyzed and taken into consideration for the study regions. Closely related works carried out in [20] presented rain rate and rain attenuation prediction in Ku and Ka bands using proprietary models designed for tropical zones while the ITU-R models were used for the rain-attenuation maps.

3.0 METHODOLOGY

3.1 Data Collection

The rainfall data used in this study were collected from the Nigerian Meteorological Agency (NIMET), Abuja. NIMET is a federal government agency charged with the responsibility of advising the federal government on meteorological issues such as weather monitoring and climatic forecast, aviation weather-monitoring support as well as the provision of monthly and annual climatic data to end-users in Nigeria. Monthly and Annual rainfall data spanning three years were (2019-2021) were filtered and processed for the locations under study. The Nigerian Metrological Agency deploys an Automatic Weather Observing Station (AWOS) system called MIDAS IV AWOS for collection of climatic data. An AWOS is an automated version of the traditional weather station which consists of a data logger, rechargeable battery and meteorological sensors attached to solar panels or wind turbine and mounted at a good height on a mast.

AWOS produces the basic weather parameters such as air temperature, relative humidity, pressure, precipitation, wind speed, wind direction and solar radiation [21]. NIMET also employs a rain gauge to further enhance accurate rainfall data collection consisting of a collection container placed in an open area. The precipitation is measured in terms of the height of the precipitated water accumulated in the container per given time and is expressed in millimetres. The upper part of the gauge consists of a cylindrical portion with an accurately turned and bevelled brass rim to which the funnel is attached. This fits closely on top of an outer case with a splayed base. Inside the outer case is a cylindrical inner can with a handle of brass wire, and the inner can is placed a glass bottle with a narrow neck. The amount of rain collected by a rain gauge is measured with the aid of glass vessels known as rain measures.

3.2 Study Locations

The locations covered in this study include four south-south tropical cities of Nigeria, namely; Port-Harcourt, Eket, Uyo and Calabar. These locations were selected based on easy accessibility of data for the region and lack of availability of rain attenuation details for efficient satellite communication link budget in the region. Table 1 presents the characteristics of the study locations.

3.3 Data Analysis

The ITU-R model is widely adopted for prediction of rain effects on communication systems. In this paper, local rainfall data collected was computed using ITU-R P618-13 rain model to obtain rain attenuation distribution from point rainfall rate values. The processing of calculated values of attenuation and rain rates were implemented using MATLAB program with the required probability of exceedance (%), with key input parameters like the specified outage time, signal operating frequency (GHz), height above sea level (km), elevation angle (degrees), latitude and longitude of the satellite earth station, radius of the earth (km) and point rainfall rates.

Table 1: Characteristics of study locations

Locations	Latitude (N)	Longitude (E)	Average Annual Rainfall (mm)	Height Above Sea Level (m)	Observation Period
Port Harcourt	4.8156	7.0498	2542	5	2019-2021
Eket	4.6467	7.9429	2508	32	2019-2021
Uyo	5.0377	7.9128	1749	45	2019-2021
Calabar	4.9757	8.3417	2739	42	2019-2021

3.4 Model Description

3.4.1 ITU-R rain attenuation model

The ITU-R P.618-13 model is presented in [22] as a widely accepted international method for the prediction of rain effects on communications systems. The ITU-R models developed is based on the rain attenuation model discussed in [23] by Dissanayake, Allnutt, and Haidara, having been shown to be the best in overall performance when compared with other models in validation studies. The computation of slant-path rain attenuation using point rainfall rate involve the following parameters:

- $R_{0.01}$: 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)
- Θ: elevation angle (degrees)
- φ: latitude of the earth station (degrees)
- f: frequency of operation (GHz)
- R_e: effective radius of the Earth (8500 km).

Figure 1 presents the slant path through rain and description of the parameters used in the corresponding step-by-step procedure for computational analysis.

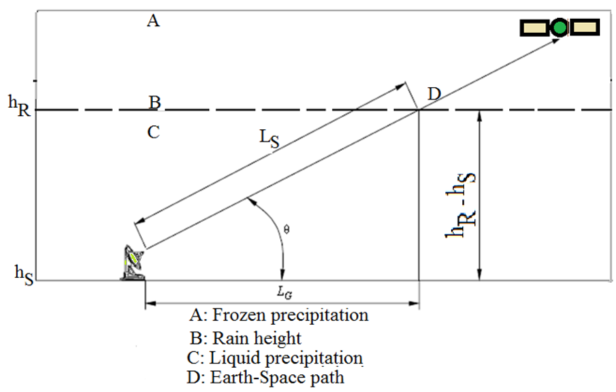

Figure 1: Slant Path through Rain [22]

Step 1: Determination the rain height, h_R, as given in Recommendation ITU-R P.839.

Step 2: Determination of the slant path length and the horizontal projection:

For $\Theta \geq 5°$

$$L_s = \frac{(h_R - h_S)}{\sin \Theta} \text{ Km} \quad (1)$$

For $\Theta < 5°$

$$L_s = \frac{2(h_R - h_S)}{\left(\sin^2 \Theta + \frac{2(h_R - h_S)}{R_e}\right)^{\frac{1}{2}} + \sin \Theta} \text{ Km} \quad (2)$$

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

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

$$L_G = L_s \cos \Theta \quad \text{Km} \quad (3)$$

Step 4: Determination of the rain rate at 0.01% for the location of interest over an average year, with an integration time of 1 min. However, if $R_{0.01}$ is equal to zero, the predicted rain attenuation is zero for any time percentage and the following steps are not required.

Step 5: Obtain the specific attenuation, γ_R, using the frequency-dependent coefficients and the rainfall rate, $R_{0.01}$. The relationship between rain rate R (mm/hr), and specific attenuation γ (dB/km) is given as:

$$\gamma_R = k(R_{0.01})^{\alpha} \quad (4)$$

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

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

Step 7: Calculate the vertical adjustment factor, v0.01, for 0.01% of the time:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_S}{L_G r_{0.01}}\right) \quad \text{Degrees} \quad (6)$$

For $\zeta > \Theta$,

$$L_R = \frac{L_G r_{0.01}}{\cos \theta} \quad \text{Km} \quad (7)$$

Else, $$L_R = \frac{(h_R - h_S)}{\sin \theta} \text{ Km} \quad (8)$$

If $|\varphi| < 36$,

$$x = 36 - |\varphi| \quad \text{degrees} \quad (9)$$

Else, $$x = 0 \quad \text{degrees} \quad (10)$$

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin \Theta}\left[31\left(1 - e^{-\left(\frac{\theta}{1+x}\right)}\right)\frac{\sqrt{L_R \gamma_R}}{f^2} - 0.45\right]} \quad (11)$$

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Step 8: The effective path length computation is as:

$$L_E = L_R v_{0.01} \text{ Km} \quad (12)$$

Step 9: Calculation of the attenuation exceeded for 0.01% of an average year

$$A_{0.01} = \gamma_R L_E \text{ dB} \quad (13)$$

Step 10: Estimation of attenuation value exceeded for other percentages of an average year, in the range 0.001% to 5%, done by the expression below:

If p 1% or $\geq |\varphi| \geq 36$:

$$\beta = 0 \quad (14)$$

If $p < 1\%$ and $|\varphi| < 36$ and $\theta \geq 25$

$$\beta = -0.005(|\varphi| - 36) \quad (15)$$

Otherwise,

$$\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta \quad (16)$$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655+0.33\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta)} \text{ dB} \quad (17)$$

[22]

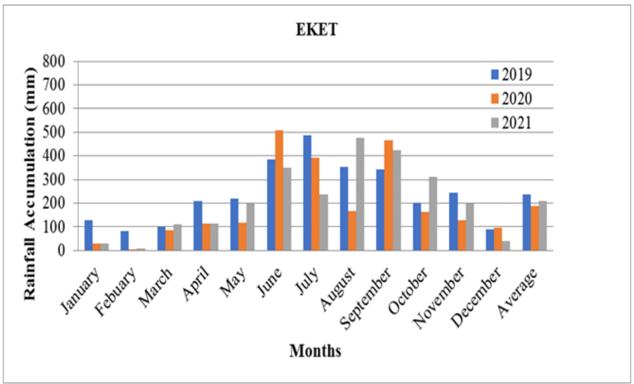

Figure 2: Monthly average rainfall accumulations for Eket.

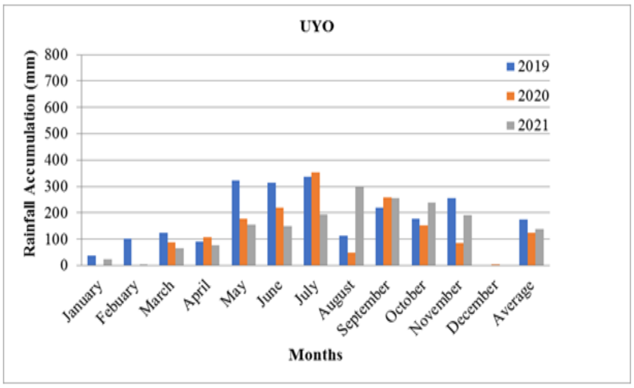

Figure 3: Monthly and average rainfall accumulations for Uyo

4.0 RESULTS AND DISCUSSION

The monthly rainfall accumulations for the south-south region of Nigeria, Eket, Uyo, Calabar and Port-Harcourt are as presented in Figure 2, Figure 3, Figure 4, and Figure 5 respectively. It can be observed in Figure 2 that rainfall events were higher between the months of April and November for the three years studied. The peak average monthly rainfall accumulation was recorded in the month of June 2020 with an average rainfall accumulation of about 192.16 mm in the same year, bringing a combined total of 7524.4 mm/hr of rainfall for the 3 years observation period. It can then be inferred that a significant level of rain fade events took place in the location between June and September each year.

Figure 3, presents monthly rainfall accumulations for Uyo. It was observed that the rainfall accumulation values were not far-off from that of Eket, but more rainfall events were recorded in the months of May to October. It recorded its peak monthly rainfall in the month of July in the year 2020, with an average rainfall accumulation of about 124.8 mm in the same year. A total of 5249.2 mm/hr of rainfall for the 3 years was calculated.

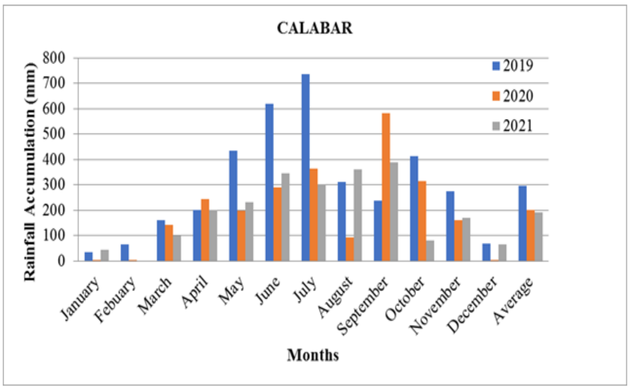

Figure 4: Monthly and average rainfall accumulations for Calabar.

Figure 4 shows the analysis for Calabar where rainfall events were very high compared to Eket and Uyo. Highest Rainfalls were recorded in the months of March to November, with a combined total of about 8218.3 mm/hr of rainfall for the 3 years observation period. It likewise recorded its peak average monthly rainfall accumulation in the month of July 2019, with an average rainfall accumulation of about 295.6 mm in the same year of 2019. It can also be inferred that significant rain induced fading events occurred in this location within those months.

Similarly, Figure 5 shows the monthly rainfall accumulation for Port-Harcourt. It was observed that rainfall was also prominent in the months of April to November with a total of 7626.8 mm/hr of rainfall for the 3 years, with peak average rainfall accumulation in September 2019, averaging 259.5 mm of rainfall in 2019.

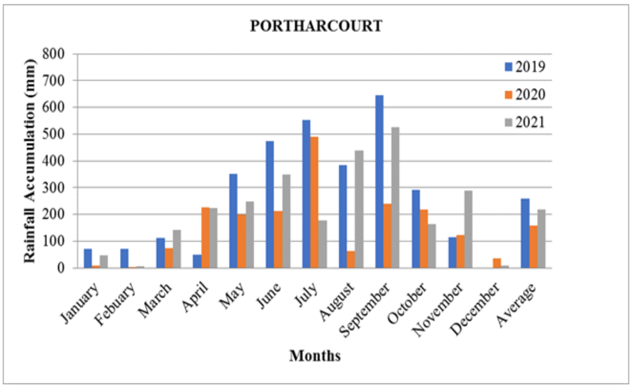

Figure 5: Monthly and Average Rainfall Accumulations for Port-Harcourt.

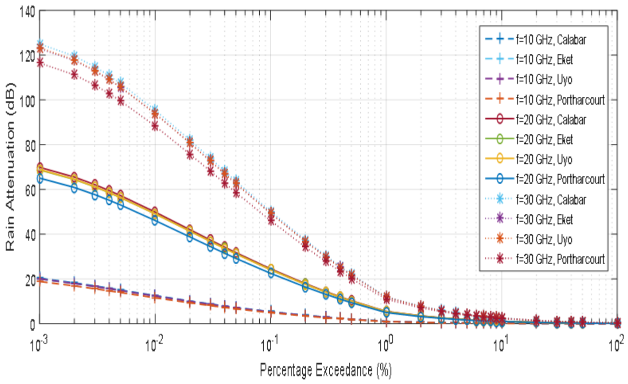

Figure 6: Variation of rain attenuation for Calabar, Eket, Uyo and Port-Harcourt at 10GHz, 20GHz and 30GHz.

The cumulative distribution of rain attenuation for the four locations is presented in Figure 6. The rain attenuation values were obtained using MATLAB program. The computed rain attenuation values were plotted for percentages of time ranging from 0.001% to 1% of average year. This was carried out at frequencies of 10GHz, 20GHz, and 30GHz. The long-term attenuation obtained for a frequency of 10GHz was found to be 18.85dB for Calabar, 18.83dB for Eket, 18.88dB for Uyo and 18.82dB for Port-Harcourt. At 20GHz, long-term rain attenuation was found to be 50.29dB for Calabar, 49.29dB for Eket, 48.33 for Uyo and 44.30dB for Port-Harcourt. At 30 GHz rain attenuation was also found to be 96.13dB, 95.20dB, 94.16dB and 88.18dB for Calabar, Eket, Uyo and Port-Harcourt, respectively. The rain attenuation for the four locations (Calabar, Eket, Uyo and Port-Harcourt) at 10GHz, 20GHz and 30GHz frequencies is presented in Figure 6.

5.0 CONCLUSION

This paper presented evaluation of rain rate and rain attenuation carried out for the cities of Port-Harcourt, Uyo, Calabar and Eket in the south-south region of Nigeria. A concise analysis of rainfall data were processed and ITU-R P618-13 model was used to obtain rain attenuation. It was found that higher frequencies variations cause higher attenuation in all the locations as shown in Figure 6. These results of higher frequencies and corresponding higher rain attenuation values shows that rain fall can cause attenuation levels due to variations of rainfall accumulation levels. The research only covered selected cities and only considered rain rate and attenuation, hence it is recommended that future works expand and considers more region and subsequently design effective mitigation techniques to compensate for rain induced signal attenuation.

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