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PERFORMANCE OF RAIN- INDUCED ATTENUATION PREDICTION MODELS FOR TERRESTRIAL LINK IN CAMEROON

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Abstract— Weather, notably rain, has a negative impact on radio wave propagation between terrestrial and earth-space links at frequencies above 10 GHz. Therefore rain-induced attenuation is a significant propagation impact that must be considered when designing satellite communication systems. Analysis of rain attenuation for earth-space links in three locations in Cameroon at V, Ku and Ka bands is investigated using four rain attenuation models: The ITU-R P.618 model, Svjatogor model, Garcia-Lopez model and Bryant model at 42.5° elevation angles. The major goal is to figure out which rain attenuation prediction models are best for satellite communication in this area. Five years (2013–2017) daily rainfall data obtained from the Tropical Rain Measuring Mission-Precipitation Radar (TRMM-PR) and Global Precipitation Measurement (GPM) mission's Core Observatory were used for this study. The results showed that the ITUR P.618, Garcia-Lopez, and Svjatogor models performed best in this region. Attenuation ranged from 15 dB to 16 at 42.5° elevation angle for time exceedance of 0.01% at Ku-band in all the study locations. For the Ka-band, attenuation varied between 32 dB and 38 dB. Signal availability at Ku-band is possible based on predicted rain attenuation values for 0.01 %-time exceedance. At Ka and V-band, the predicted rain attenuation values for 0.01%-time exceedance have shown that availability of signal is impossible, which infers losses of the signal during such rainfall events across the selected locations in Cameroon

Keywords— Attenuation, models, Terrestrial, frequency.

I. INTRODUCTION

Due to mobile data demands by network service providers, increasingly evolving wireless networking networks are starting to use millimeter-wave frequency bands (30-300 GHz) to transmit data at an increasing rate. Vapor, fog, oxygen, rain, and several other gases that make up the air cause attenuation of propagation in microwave communication systems. Rain-induced attenuation is the most extreme of these distinct atmospheric components [1]. The propagation attenuation due to rainfall is further increased if a high-frequency band of 10GHz and above is used [2]-[3]. Rain attenuation has caused

the use of frequencies of 10 GHz and above in satellite connections for commercial operations in tropical countries limited. [4]. Rain attenuation experienced in these areas is caused by considerably higher rainfall rates and bigger raindrops sizes compared to other parts of the world [5]. The attenuation will pose a greater problem to communications as the frequency of occurrence of heavy rain increases. In tropical regions like Cameroon, excessive rainfall is a frequent phenomenon throughout the year. The awareness of the rain attenuation at the desired frequency of operation is a critical necessity for designing reliable terrestrial and earth-space communication links.

The attenuation that results from absorption by raindrops is larger than the attenuation from scattering at smaller wavelengths in comparison to the drop size, while the attenuation resulting from scatter is enormous than losses resulting from absorption for wavelengths that are longer in comparison to the raindrop size [6]. Rain attenuation depends on rain rate, terminal velocity, size distribution and shape of the raindrops [7]. Satellite beacon signals and radiometers can estimate attenuation due to rain, but the results obtained cannot be directly adopted for all locations. Such propagation tests are carried out only in very few places and for a small number of frequencies and link geometry worldwide.

On any microwave link, there are two large groups of rain attenuation predictions: analytical models based on physical laws governing the propagation of electromagnetic waves that attempt to replicate the actual physical behaviour in the attenuation process; and empirical models based on measurement databases from stations in different climatic zones within a given area [8, 9]. The emphasis of this paper is to compare the attenuation threshold obtained with other rain attenuation prediction models built based on tropical region characteristics. It is to see whether these models can be used to predict rain attenuation for signals that have the same parameter configurations as these data. Hence, various attenuation models based on empirical facts and the use of available meteorological data have been developed to provide enough inputs for system margin calculations in every region of the world [10, 11]. This implies that accurate prediction of rain-induced attenuation on propagation paths is imperative



when planning both microwave and terrestrial line-of-sight system links [12].

Cameroon, a country in the West African sub-region and being situated in the tropics is prone to signal attenuation due to rain and NIGCOMSAT-IR, a Nigeria satellite which also effectively covered the telecommunication services in Cameroon is connected with other satellites like the Sat ADLS launched in 2018 in addition to the AMOS fleet operate on Ku and Ka- bands. The rapid growth in telecommunication demand now makes engineers to explore the usage of the V band. It is therefore of utmost necessity to estimate the rain attenuation which will be a major factor in guiding the design of communication devices in the selected locations in Cameroon.

In this study, the Bryant, Garcia, and Svjatogor models have been selected to be compared with the ITU-R model using data obtained from the GPM satellite data.

II. STUDY BACKGROUND

Rain rate models are used to forecast the cumulative distribution of point rainfall rates at any place. There are a number of such models available. Some of them, however, have inconsistencies, such as the amount of stations and data provided, and not all of the stations meet the one-minute integration time criteria [13]. Some applications necessitate a high density of short integration times. [12]. [14] devised a method for calculating rain rate numbers that may be used in fading calculations. The model necessitates inputs such as the greatest monthly rainfall accumulation during a 30-year period, in a typical year, the average yearly accumulation and the number of thunderstorm days are expected. Local weather agencies do not usually provide the thunderstorm ratio, which is a limitation. This model, on the other hand, overestimates rain rates in the high availability range of 0.01 percent and underestimates rain rates in the low availability range of 0.1 percent and 1%. [15]. According to recent research, a model that approximates a log-normal distribution at low rates and a gamma distribution at high rate is more suited to characterize the rain rate distribution. The rain rate model developed by Moupfouma and Martins is suitable for both tropical and temperate climates. [16] expressed this as:

$$P(R \geq r) = 10^4 \left(\frac{R_{0.01}}{r+1} \right)^b \exp(\mu(R_{0.01}-r)) \quad (2)$$

P denotes the likelihood of a rain event occurring 0.01 percent of the time, r (mm/h) represents the rain rate surpassed for a fraction of the time, and R_{0.01} (mm/h) represents the rain intensity surpassed for a fraction of the time during 0.01% of time in typical year and b is approximated by the following expression [17]:

$$b = \left(\frac{r-R_{0.01}}{R_{0.01}} \right) \ln \left(\frac{1+r}{R_{0.01}} \right) \quad (3)$$

The parameter μ , which is dependent on local climate conditions and geographic factors, determines the slope of the rain cumulative distribution. When it comes to tropical and subtropical climates,

$$\mu = \frac{4 \ln 10}{R_{0.01}} \exp \left(-\lambda \left(\frac{r}{R_{0.01}} \right) \right) \quad (4)$$

The rain rate exceeded for 0.01 percent of the period is calculated using [18] model, parameters $\lambda = 1.066$, $\Upsilon = 0.214$. From the long-term mean annual rainfall rate, the improved Moupfouma model can be used to calculate the one-minute rain rate cumulative distribution.

Also, Various methods were developed for the calculations of cumulative distributions (CDs) of rain attenuation due from rain rate measurements [19, 20]. The ITU-R recommendation [20] considers the time-space variability of rain intensity along the terrestrial path by using an effective path length. The average 1-minute rain intensity exceeded at the same time percentage is used to compute rain attenuation that exceeded 0.01 percent of the time of the year. The empirical formula is used to scale the acquired value to different percentages of time between 1% and 0.001%. [21].

Rain attenuation can be measured directly using microwave links or calculated using data on rain rate and rain drop size distribution. [22] presented a methodological approach for calculating rain-induced attenuation from available precipitation data, using the moment of regression method to estimate the number of drop sizes and comparing the findings to a log-normal distribution. However, as previously indicated, the bulk of rain attenuation estimates in tropical locations are now based on the Moupfouma model, which is suitable for both temperate and tropical climates.

A. Rain rate

R 0.01 input is necessary for rain attenuation prediction. Chebil and Rahman are a couple. The model employed in this work converts rain amount data from any location to equivalent rain rate data, regardless of the integration time of the available rain data. It is calculated using a long-term mean annual accumulation, M, of rain gathered at the study location, which is stated as:

$$R_{0.01} = \alpha M^\beta \dots\dots\dots (5)$$

Where α and β are regression coefficients and are 12.2903 and 0.2973 respectively.

M represent the total rain fall measured for a year and rain rate R_{0.01} is measured in mm/h [18])

B. Attenuation models

In this work, four rain attenuation models were carefully chosen for comparison. The Garcia-Lopez [23] Bryant model [24], Svjatogor model [25], and [20] established step-by-step approaches for determining rain attenuation over the Earth-satellite radio link [26]. Each model is described below.



1. García-López Model

[23] produced a rain attenuation model for satellite links as a follow-up to the one provided for terrestrial links, which was based on measurements taken over satellite links in Australia, United State, Europe, and Japan. The coefficients used in the attenuation calculation are provided individually for tropical nations [27]. In a satellite link, rain attenuation A (dB) is calculated as :

$$A = \frac{kR_p^\alpha L_s}{\left[a + \left[L_s \frac{(bR + cL_s + d)}{e} \right] \right]} \quad (6)$$

2. Bryant Model

To compute the distribution of rain attenuation, the Bryant model uses the concept of an effective rain cell and changing rain height [24]. Calculation of the attenuation along the slant path which is given as [28]:

$$A_s = 1.57 D_m K_n \gamma_p \frac{L_s}{\xi_{L+D}} \quad (7)$$

3. Svjatogor Model

The svjatogor model [25] defines its effective rain height, H_R, depending on the rain intensity as:

$$H_R = \frac{2.7}{\log_{10}(0.2R_p + 1.5)} + 0.0015 R_p \text{ (km)} \quad (8)$$

The rain attenuation A_s is given as:

$$A_s = kR_p^\alpha L_s K_{rs} \text{ (dB)} \quad (9)$$

4. ITU-R Model

[20] gives summarised procedures for the computation of satellite path rain attenuation as follows:

- i. Obtain the specific attenuation, \square_{RR} , using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, R_{0.01}, determined from Step 4, by using:

$$\square_{RR} \square k \quad (R_{0.01}) \square \text{ dB/km} \quad (10)$$

The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} \square \square R L_E \text{ dB} \quad (11)$$

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

$$A_p = A_{0.01} \left(\frac{p}{0.01} \right)^{-(0.655 + 0.033 \ln(p) - 0.045 \ln(A_{0.01}) - \beta(1-p) \sin \theta)} \text{ dB}$$

III. METHODS AND ANALYSIS

The data were collected from Tropical Rain Measuring Mission-Precipitation Radar (TRMM-PR) and Global Precipitation Measurement (GPM) mission's Core Observatory for three locations in Cameroon namely ; Maraoua, Touboro, and Kumbaloum, from January 2013 to December 2017. Parameter settings are listed in Table 1. The TRMM and GPM are American–Japanese earth satellite observatory missions. TRMM was launched in November 1997 and placed at an altitude of 350 km, later extended to 402.5 km. The TRMM was succeeded and improved upon by the GPM mission launched in 2014. Both missions, TRMM-GPM, were established to provide a comprehensive knowledge of the nature of precipitation, snow, and radiation in the tropical regions of the earth (Acker and Leptoukh, 2007; Simpson et al., 1996).

The Tropical Rainfall Measuring Mission (TRMM), operating in a non-sun-synchronous orbit, it has an orbital period of 91 min, making 16 orbits per day, to provide good coverage of the tropics.

Table 1 : Geographical characteristics of locations in this study

Locations	Longitude (°E)	Latitude (°N)	R _{0.001}	h _s (m)	Elevation angle (Θ)	Average annual rainfall (mm)	Horizontal L _E (km) at f (GHz)		
							Ku (f= 15)	Ka (f= 30)	V (f= 60)
Maroua	14.336	10.765	94.84	414	67.7	966.2	3.103	3.585	4.309
Touboro	15.220	7.795	122.58	545.3	60.4	2290.9	2.687	3.213	4.022
Kumbaloum	9.393	4.650	153.62	250.3	51.5	4892.3	2.531	3.156	4.163

L_E = Effective Path length and H_s = Height above sea level

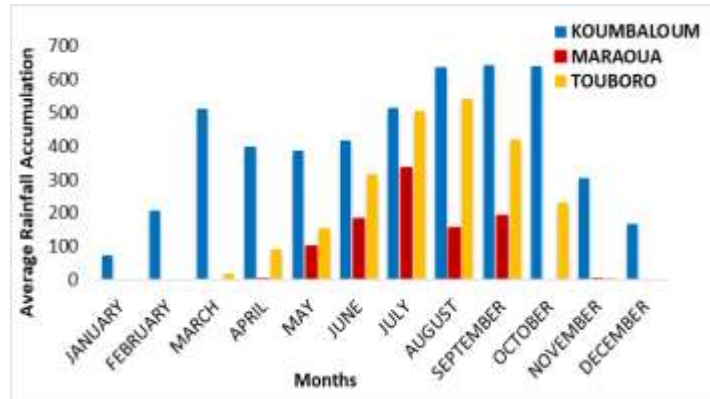


Figure 1 : Five years monthly average rainfall accumulation in study locations

Table 2 : Rain rate Analyses at different percentages of time in different locations of study

Cities	Percentage exceedance							
	0.001	0.01	0.03	0.05	0.1	0.3	0.5	1
Koumbaloum	165	120	98	89	75	63	50	17
Touboro	140	91	84	58	42	22	14	7
Maraoua	128	88	73	52	32	26	10	5.2

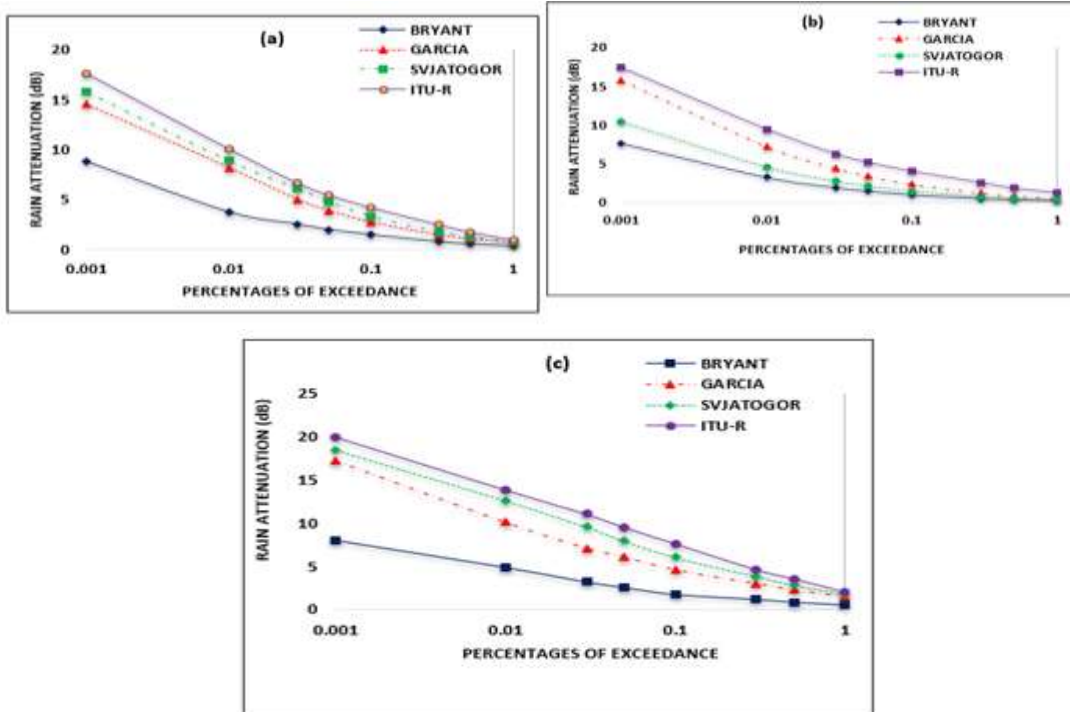


Figure 2: Cumulative distributions of rain attenuation distribution at Ku-band (15 GHz) frequency in (a) Maraoua, (b) Touboro, and (c) Koumbaloum

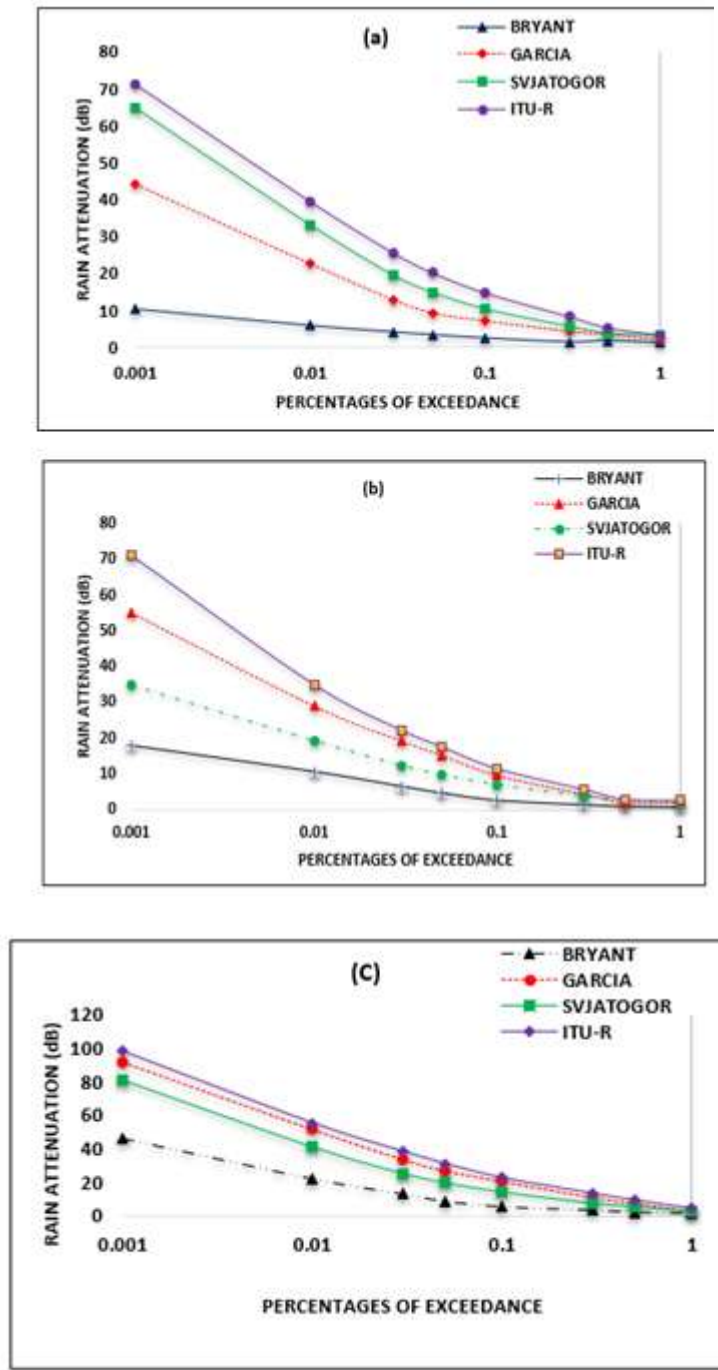


Figure 3: Cumulative distributions of rain attenuation distribution at Ka-band (30 GHz) frequency in (a) Maraoa, (b) Touboro, and (c) Kumbaloum

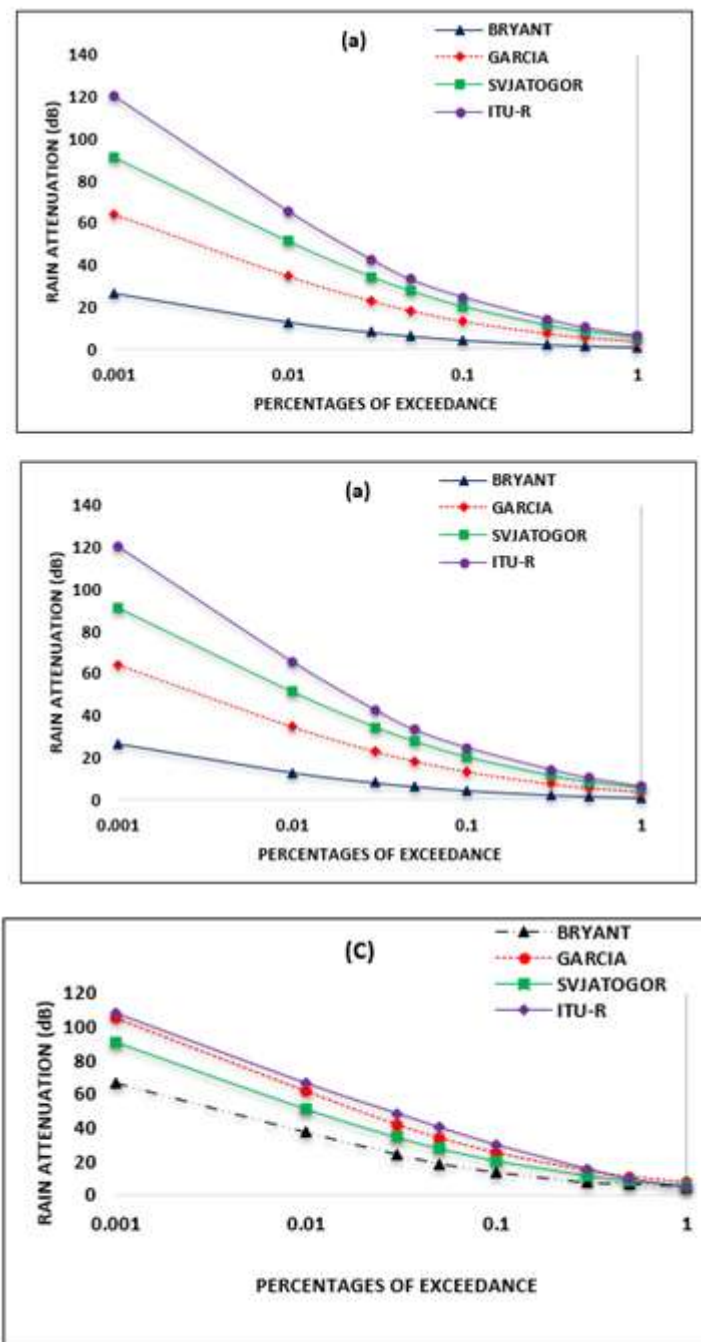


Figure 4: Cumulative distributions of rain attenuation distribution at V-band (60 GHz) frequency in (a) Maraoua, (b) Touboro, and (c) Kumbaloum

IV. RESULTS AND DISCUSSION

The rainfall analyses from the long-term daily rainfall data for the three selected locations in Cameroon are presented. The data were collected for the period of 5 years (January 2013 to December 2017).

A. Rainfall distribution in locations of study

The rainfall monthly distribution across the study location is as shown in Figure 1. Cameroon recorded the total accumulated rainfall of 4892.3. monthly distribution shows that Koubaloum recorded its peak as the highest rainfall in June, July and August with 415mm, 513mm and 634. Touboro also recorded peak average monthly rainfall accumulation in



the month of July, August and September with 506 mm, 539 mm, 420 mm while Maroua recorded the lowest rainfall having its peak in July with 333mm.

During the observation period, rainfall was often low during the dry season, which began in November and typically ended in March, whereas rainfall was projected to be higher during the wet season, which runs from April to October. These months with the highest rainfall are the worst months for a radio hookup in the various places (Rafiqul et al., 2018; Ojo and Ajewole 2008).

Also, the observed seasonal rainfall variation is attributed to the prevailing weather conditions in the area under study: During the dry season, the entire country is under the influence of dry continental air because of the dry and cold North Easterly tropical continental (cT) air mass over the region which is often accompanied by dust particles transported from the Sahara desert, which coincides with a period of minimum or no rain. In the wet season period, the deep moist maritime air predominates along with the characteristic heavy rainfall from the South-Westerly, tropical maritime (mT) air mass bringing moisture on to the country from the Southern hemisphere (Ojo, 1977).

The study location characteristics including the average annual rainfall for 5 years and the computed point rainfall rate R0.01 are given in Table 1, while table shows the rain rate at different percentages of times of signal availability within the specified period.

B. Rain attenuation prediction

The point rainfall rate computation by the Chebil model was used as initial input to predict the rain attenuation from the four rain attenuation models employed. The cumulative distributions of the rain-induced attenuation obtained at different percentages of time were compared for each of the stations. The frequencies used are 15 GHz for the Ku-band, 30 GHz for the Ka-band, and 60 GHz for the V-band. The 42.5°, which is the elevation angle of NIGCOMSAT-1R over the Atlantic Ocean Region, was considered for this work. The ITU-R model is the most widely accepted method for estimating rain attenuation on satellite communication systems all over the world. Hence developed models are compared with reliability, especially when measured data are not available (Lekkla, and Prapinmongkolkarn, 1998). Results from experimental data have shown that the ITU-R rain attenuation prediction model, which was derived based on lognormal distribution, agrees closely with measured values (Parth and Rutvij 2016; Ojo et al., 2008; Choi et al., 1997; Nalinggam and

Mandeep; Panchal and Joshi, 2016). As a result of this global acceptability of the ITU-R model, comparisons carried out in this work were based on the model. Tables 1 show results for the computed geometric parameters relevant to satellite links at Ku, Ka and V frequency bands. The cumulative distributions of the rain-induced attenuation obtained for the Ku-band at 42.5° elevation angle for the three stations using

the different attenuation models were compared. Figure 3(a)–(c) shows the comparison for each of the stations. As shown in Fig. 3(a)–(c), the Svjatogor and Garcia-Lopez models predicted closely with the ITU-R model, while the Bryant model underestimated the predicted rain attenuation values. For instance, at Ka-band, the rain attenuation predicted by the ITU-R model for 0.001% exceedance probability is 46 dB, 36 dB, and 31 dB for Kumbaloum, Touboro, and Maroua, respectively while Garcia-Lopez model at this same percentage of the time, predicted 32 dB, 15 dB and 17 dB for Kumbaloum, Touboro and Maroua. Bryant model predicted 14 dB, 7 dB and 10 dB for Kumbaloum, Touboro, and Maroua, respectively, while the Svjatogor model predicted 38 dB, 20 dB, and 10.5 dB for Kumbaloum, Maroua, and Touboro, respectively. At 0.01%, the ITU-R model predicted 22 dB, 18 dB, and 16 dB for Kumbaloum, Touboro, and Maroua. The corresponding attenuation predicted Svjatogor model is 19 dB, 7 dB, and 4 dB. Garcia-Lopez model's prediction is 16 dB, 7 dB and 8 dB for Kumbaloum, Touboro and Maroua. The predictions from the Bryant model were much lower as they underestimated the rain attenuation at the exceedance percentage of time considered in all the locations.

The cumulative distribution of the rain-induced attenuation at Ka band was also examined at 42.5° elevation angle. The results are presented in Fig. 4(a)–(c). The results show that attenuation values are higher at this frequency for all the models and at all the stations. At 0.01 in Maroua, 85 dB, 76 dB, 54 dB, and 22 dB were predicted by ITU-R, Svjatogor, Garcia-Lopez and Bryant models respectively. In Touboro, 72 dB, 52 dB, 43 dB, and 18 dB were predicted by ITU-R, Svjatogor, Garcia-Lopez and Bryant models respectively. In Kumbaloum 95 dB, 84 dB, 71dB and 51 dB were also predicted by ITU-R, Svjatogor, Garcia-Lopez and Bryant models respectively. Here, the Garcia-Lopez and Svjatogor models still predicted closely with the ITU-R model while the Bryant model underestimated the attenuation. Kumbaloum recorded the highest attenuations, followed by Touboro and Maroua.

Fig. 5(a)–(c) show that rain attenuation at V-band is significantly higher than at Ku and Ka-band for all the locations which is due to the longer path length at this elevation angles. The predicted rain attenuation by ITU-R model exceeded for 0.001% of the time is as high as 250 dB, 125 dB and 96 dB in Kumbaloum, Maroua and Touboro respectively. Also, at 0.01% of time, the rain attenuation predicted varies between 112 dB and 72 dB at the 54 dB at Ka-band frequency. Although, it is observed that none of the models predicted as high as the ITU-R model at the study locations. For the Ka-band, the values predicted by the Garcia-Lopez and the Svjatogor models were close to each other. It is clear, based on the observations, that the ITU-R, Garcia-Lopez and the Svjatogor models can satisfactorily be used to predict rain attenuation at Ku-band, while the ITU-R model can conveniently predict rain attenuation at Ka-band and V band in this region. The Bryant model is unsuitable for rain



attenuation prediction in this region. Also, the predicted attenuation values at exceedance probability of 0.01% for the Ku band reveal that 99.99% availability (about 53 min outage in a year) of signal is possible at Ku band since attenuation values are less than 20 dB, but there will be total fade out of signals at the Ka and V-band during rainfall in all the stations since the predicted attenuation values are much greater than 20 dB. This conclusion stems from the fact that most satellites operating at 10 GHz and above are designed to withstand attenuation that are less or equal to 20 dB on its link because of restricted carrier power at the output of the transmission amplifier. It is about 150 W and minimal battery power onboard the spacecraft.

V. CONCLUSION

Rain attenuation and its impacts on satellite communication in the Ku, Ka, and V bands have been researched for three locations in Cameroon for satellite links operating at 42.5° elevation angles. Four distinct rain attenuation models were used to make these forecasts. Kumbaloum has the highest attenuation values across all the stations at all the considered frequency bands; this is definitely due to its closeness to the coastal line and a longer path length. Signal availability is possible at Ku but impossible at Ka and V bands, meaning there will total signal fade out during rainstorm events in all stations, based on estimated attenuation values of 0.01 percent, which is comparable to 99.99 percent availability (approximately 53 minutes downtime per year). The results reveal that the ITU-R P.618 model, Garcia-Lopez, and Svjatogor attenuation models are suitable for predicting rain attenuation at Ku, and Ka-band in this region of Cameroon, whereas the ITU-R model can be utilized to predict rain attenuation at V-band.

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