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Validation of Rain Attenuation Models with Experimental Data at Covenant University, Southwest, Nigeria

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Abstract

The estimation of rain attenuation at frequency above 10 GHz is very vital for proper calculation of the fade margin to mitigate such effect in any locality. The ground rain attenuation measurement obtained from an earth-space path link, mounted at Covenant University, Ota, Nigeria is presented in this paper. The receiving antenna dish is pointed to a geostationary satellite (Astra 2E/2F/2G, 28ºE) at frequency 12.245 GHz to monitor Data-To-Home (DTH) downlinks. The cumulative distribution function for different rain attenuation events have been generated from the measured 4-year spectrum analyser data. The result was also compared with fourteen existing rain attenuation models around the world. The result shows that the average four-year rain attenuation obtained at 0.001 %, 0.01 %, 0.1 % and 1 % are 4.66 dB, 4.01 dB, 3.31 dB and 2.51 dB respectively. This result did not agree with theoretical rain attenuation values obtained using the existing models for rain attenuation except for SAM model. The result of the study will make available relevant information for microwave engineers for the estimation of rain attenuation on microwave links in Ota, southwest Nigeria which can be used to project for regions with the similar climatic conditions and calculate the best fade margin to mitigate the effect of attenuation due to rain to satellite signals in the region.

Keywords: frequency; propagation; rain rate; rain attenuation; satellite; southwest Nigeria

1. INTRODUCTION

The propagation of communication signals at frequency from 10 GHz and above offer a wide range of benefits which include high data rate, increased bandwidth, etc. Attenuation of communication signals at microwave frequency is a major concern to communication system experts/engineers [1]. This impairment causes loss of signals due to obstacles encountered along the propagation path. The major obstacle that causes severe degradation of signal amongst others is rain [2]. Rain affects communication signals as it propagates through the troposphere either by absorption and/or scattering. A reliable mitigation of rain attenuation in a locality for a reliable access to robust communication signal requires an adequate understanding of the nature of rainfall (i.e. intensity and accumulation) in such locality. Rainfall differs geographically depending on the process of its formation. The events of rainfall in the tropics differs greatly from that of the temperate region. The tropics is known for intense occurrence of rainfall which results in high rainfall rate compare to the temperate region [3-6]. Rain attenuation has a linear relationship with rain rate as expressed in equation 1. Several researchers have established models used to evaluate one-minute rainfall attenuation distribution globally [7-18]. The methodical procedure of each model for the estimation of rain attenuation can be obtained from [19]. Rain attenuation estimation and prediction in the tropics like Ota for calculation of proper fade margin is limited due to dearth of rain attenuation measurements in such locations. These existing prediction models have been used to predict attenuation values. For a proper prediction, ground measured data must be used to validate the theoretically obtained attenuation values from the existing prediction models. This comparison with measured rain attenuation results obtained from tropical regions has been on going [20-25]. The information from these results will serve as an extensive understanding of rain attenuation effect in this locality. Hence, microwave engineers can use the result as a good preliminary tool for both terrestrial and earth-space path links.

$$\gamma = \alpha R^{\beta} \qquad (1)$$

where γ is the specific rain attenuation, R represents rain rate in mm/hr, α and β are empirical coefficients that depends on frequency and polarization which are determined from [26].

2. METHODS AND EXPERIMENTAL DATA

Rainfall data was collected using rapid response tipping bucket rain gauge with a 1-minute integration time from January 2012 to December 2017. The direct measurement of rain attenuation of received signal was achieved. This measurement is obtained by pointing directly to a geostationary Astra satellites (Astra 2E/2F/2G) positioned at 28.2 °E. The block diagram of the experimental setup is shown in Figure 1. The Earth station for digital Data-To-Home (DTH) reception is monitored from the ASTRA 2E/2F/2G (28.2 °E) to which a parabolic offset VSAT

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receiver antenna dish is pointed to. The satellite dish is installed on the rooftop of College of Science and Technology (CST) building of Covenant University (CU), Ota, Nigeria (6.7˚N, 3.23˚E) at a 52 m above the sea level as shown in Figure 2. The angle of elevation of the receiver antenna and the beacon fixed frequency are 59.9˚ and 12.245 GHz respectively. The antenna is vertically polarized for transmission by the satellite for reception to the ground station. The dish consists of a low noise block converter (LNBC) of 0.9 dB noise figure. This is utilized to down-convert all the three sub-bands of the Ku-band downlink (10.70 – 12.75 GHz). Two L-band ranges were used remotely through an automatic 22 kHz tone control. It is highly stable and offer low noise. It is connected to a spectrum analyzer and interfaced to a computer [27] observed that satellite beacon signal transmission measurements are the most popular and offers wider range. Table 1 shows the characteristics of the ground measurement station. The beacon signal strength of the receiver antenna is measured using the spectrum analyser device at one-minute interval level.

The total percentage of available data during the observation period was not 100 % possible due to power outage experienced especially in 2017. The signal strength of the received signal with date and time during clear sky and rainfall events were recorded and analysed. The date, time and receiver channel power respectively were extracted from the raw data recorded from the spectrum analyzer for rainy days. The data was treated. This could probably be due to system malfunctioning during tropospheric propagation of microwave signals. All of these were filtered out from the raw data. The monthly average measured received signal power under clear sky condition were computed. To compute the attenuation, this value was subtracted from the received signal power during rainfall.

A pivot table was used to obtain the frequency of occurrence of each measured rain rate and attenuation value. From which the cumulative frequency distribution, cumulative percentage and probability distribution function were estimated. The cumulative probability distribution which is also known as the exceedance curve is for the determination of the long-term behaviour of the measured rain rate and attenuation. The probability distribution function is used to determine the percentage of time in a year that the measured attenuation is exceeded at a specific value. The percentage of time considered in this research work were 0.001 %, 0.01 %. 0.1 % and 1 %. ORIGIN 8.0 computer programme was used to plot the cumulative distribution curve for the measured rain rate and rain attenuation under study to determine the probability of exceedance value and to estimate the probability of time an outage will occur. The rain rate obtained, and other parameters were fitted into the existing attenuation models to obtain the theoretical values of rain attenuation. This was compared with the measured rain attenuation. The outcome of the experimental measurements is presented.

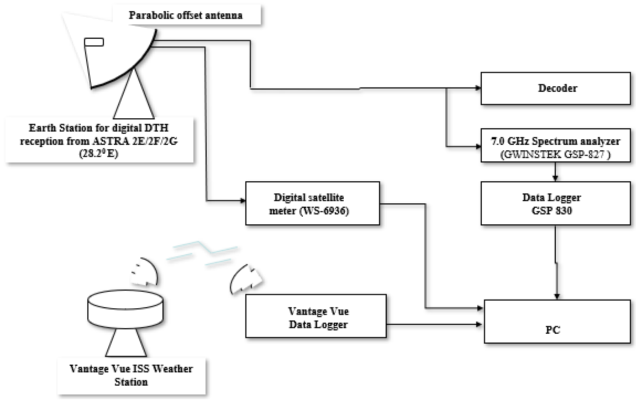

Figure 1 Block diagram of the experimental setup at Covenant University, Ota

Figure 2 The outdoor of the satellite dish pointing to space and the tipping bucket rain gauge

Table 1 Characteristics of ground measurement station

S/N	Parameter	Specifications
1	Satellite in space	Astra 2E/2F/2G at 28.2ºE
2	Beacon frequency (GHz)	12.245
3	Polarization of the signal	Vertical
4	Antenna elevation (degree)	59.9
5	Altitude of site (m)	74
6	Antenna diameter (m)	0.9
7	Height of antenna (m)	5.9
8	Antenna Gain	60 dB
9	Latitude (˚N)	6.7
10	Longitude (˚E)	3.23

3. RESULTS AND DISCUSSIONS

The rainfall rates obtained at different percentage of time from the empirical measurement for six years (2012 – 2017) at Covenant University, Ota, Ogun State, Nigeria were used as the major input parameters to compute the rain attenuation for all the predicted models. The rain height obtained from measurement was also used instead of the one predicted by ITU-R to obtain the predicted value of rain attenuation. The graph of rain attenuation plotted against probability of percentage of exceedance for each rain attenuation model for 2012 to 2017 is presented in Figures 3 to 6. The curves plotted were used to estimate the probability of outage for 0.001% to 1% from 2012 to 2017.

The characteristics of the site's propagation measurement used for estimations are shown in Table 1. The rainfall rate at 0.001%, 0.01%, 0.1% and 1% unavailability of time and other parameters were also used to compute the rain attenuation. Figures 3 to 6 show the plot of 14 predicted and existing rain attenuation models for 2014 to 2017 in CU, Ota at frequency 12.245 GHz from the actual measurements. The existing prediction models uses step by step procedures to obtain the rain attenuation exceeded for any percentages of an average year from the rainfall rate exceeded of 0.001%, 0.01%, 0.1% and 1% of an average year. The standard prediction models calculate the rain attenuation in dB. Figure 3a shows that on the average the result of rain attenuation obtained using the Assis-Einloft model [7] are 26.74 dB, 21.79 dB, 10.43 dB and 1.63 dB at 0.001%, 0.01%, 0.1% and 1% respectively. Figure 3b shows that on the average the result of rain attenuation obtained using the Australian model [8] are 12.62 dB, 5.82 dB, 1.71 dB and 0.09 dB at 0.001%, 0.01%, 0.1% and 1% respectively.

Figure 4a shows that on the average the result of rain attenuation obtained using the Brazil model [9] at the respective (0.001%, 0.01%, 0.1% and 1%) percentage of time are 35.28 dB, 20.44 dB, 6.75 dB and 0.56 dB. Figure 4b shows that on the average the result of rain attenuation obtained using the Bryant model [10] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 12.62 dB, 5.82 dB, 3.81 dB and 0.09 dB. Figure 4c shows that on the average the result of rain attenuation obtained using the Crane Global model [11] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 49.02 dB, 16.66 dB, 3.81 dB and -0.27 dB. Figure 4d shows that on the average the result of rain attenuation obtained using the Crane Two Components model [12] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 12.62 dB, 5.82 dB, 3.81 dB and 0.09 dB.

Figure 5a shows that on the average the result of rain attenuation obtained using the EXCELL model [13] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 97.54 dB, 90.75 dB, 86.63 dB and 85.01 dB. Figure 5b shows that on the average the result of rain attenuation obtained using the Garcia model [14] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 19.96 dB, 14.68 dB, 6.94 dB and 0.51 dB. Figure 5c shows that on the average the result of rain attenuation evaluated using the ITU-R 618-13 model [15] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 22.26 dB, 14.73 dB, 6.67 dB and 1.37 dB. Figure 5d shows that on the average the result of rain attenuation obtained using the Karasawa model [9] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 35.04 dB, 17.39 dB, 6.18 dB and 1.58 dB.

Figure 6a shows that on the average the result of rain attenuation obtained using the Leitao-Watson Showery model [9] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 18.16 dB, 9.57 dB, 3.43 dB and 0.29 dB. Figure 6b shows that on the average the result of rain attenuation obtained using the Misme Waldteufel model [16] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 30.78 dB, 40.33 dB, 20.57 dB and 3.31 dB. Figure 6c shows that on the average the result of rain attenuation obtained using the SAM model [17] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 7.09 dB, 3.79 dB, 1.35 dB and 0.10 dB. Figure 6d shows that on the average the result of rain attenuation obtained using the Svjatogor model [18] at the respective percentage of time (0.001%, 0.01%, 0.1% and 1%) are 20.99 dB, 10.82 dB, 4.29 dB and 0.68 dB.

The attenuation values obtained from the existing predicted models are higher than the rain attenuation measured at all percentage of time. Using ITU-R model to predict rain attenuation values for microwave signal in the tropics where higher rainfall rate exist, does not reveal quite good result [28]. This could probably be because ITU-R prediction model perform very well for regions with low rain rate and low elevation angles. The elevation could be as low as 25° and below. Also, derivation of slant path length in the temperate region would differ considerably from the tropics due to difference in rain height.

It is clearly detected that the results obtained from the existing predicted models do not agree with the measured rain attenuation in Covenant University, Ota. The rainfall distribution experienced in some tropical station shows similar results [29-31]. The rainfall rate obtained in tropical regions like Covenant University, Ota are higher than that obtainable in the temperate regions [32]. Another reason for the disagreement in the results could possibly be the variation in the rain height. In other several models for example rain height correction factor and the effective rain height in Waldteufel model and Karasawa model respectively differs. Moreover, the existing rain attenuation predicted measurement and modelling were mostly focussed in the temperate zone. Also decrease in the predicted attenuation is first noticed as the elevation angle increases [33]. At the location of study (Covenant University, Ota.), the reverse is the case as the angle of elevation becomes appropriately high.

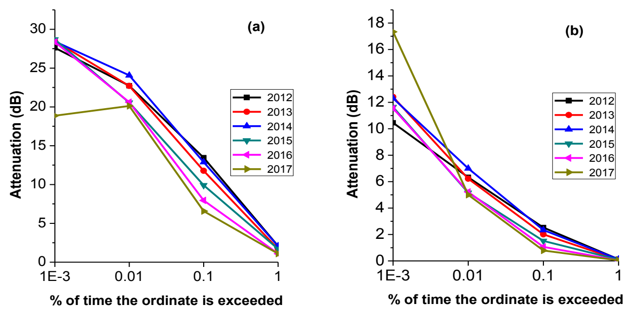

Figure 3 The probability of exceedance curve computed for each rain attenuation model (a) Assis-Einloft Model and (b) Australian Model

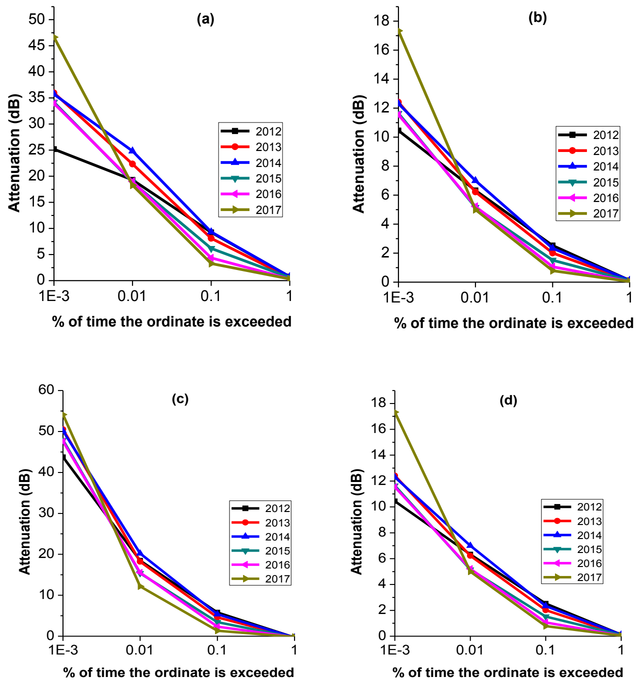

Figure 4 The probability of exceedance curve computed for each rain attenuation model (a) Brazil Model and (b) Bryant Model (c) Crane Global Model and (d) Crane Two Components Model

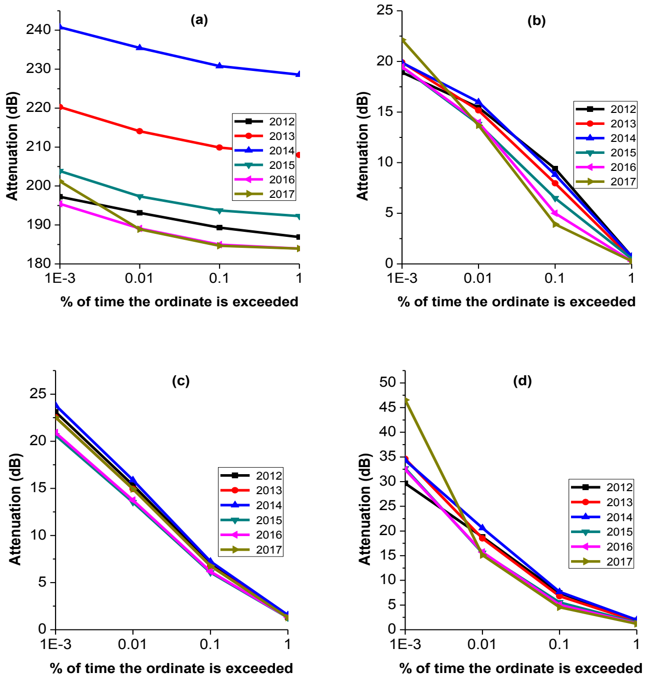

Figure 5 The probability of exceedance curve computed for each rain attenuation model (a) EXCELL Model and (b) Garcia Model (c) ITU-R 618-13 Model and (d) Karasawa Model

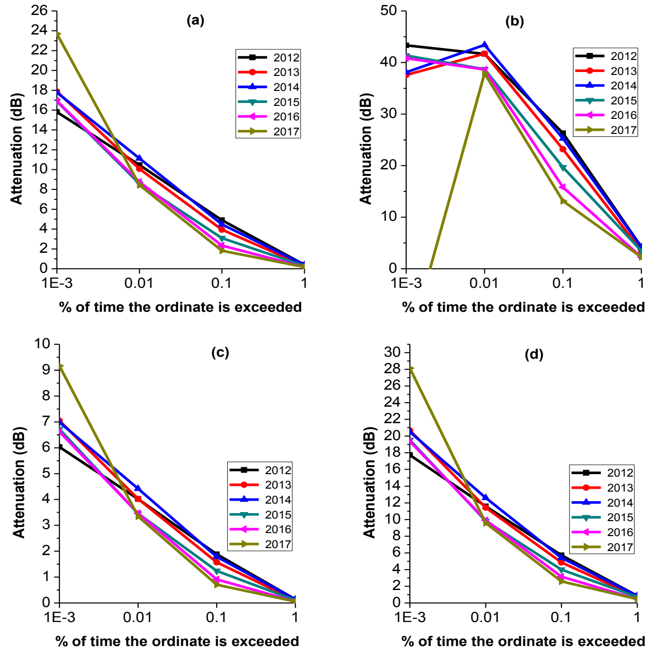

Figure 6 The probability of exceedance curve computed for each rain attenuation model (a) Leitao-Watson Model and (b) Misme Waldteufel Model (c) SAM Model and (d) Svjatogor Model

The graphical comparison between predicted rain attenuation models and measured rain attenuation values at 0.001%, 0.01%, 0.1% and 1% of time (i.e. probability of exceedance is presented in Figure 7.

As revealed in Table 3, on the average, the measured rain attenuation obtained for Covenant University, Ota at 0.001%, 0.01%, 0.1% and 1% of time are 4.64 dB, 4.01 dB, 3.32 dB and 2.51 dB respectively. The exceedance probability of 0.01 % is of great importance to microwave engineers being the acceptable outage of communication signal in an average year. In Covenant University, Ota, the measured attenuation at 0.01 % is 4.01 dB while the corresponding estimated predicted values are 21.79 dB (Assis-Einloft); 5.82 dB (Australian); 20.44 dB (Brazil); 5.82 dB (Bryant); 16.66 dB (Crane Global); 5.82 dB (Crane Two Components); 90.75 dB (EXCELL); 14.68 dB (Garcia); 14.73 dB (ITU-R Rec 618 – 13); 17.39 dB (Karasawa); 9.57 dB (Leitao-Watson Showery); 40.33 dB (Misme Waldteufel); 3.79 dB (SAM) and 10.82 dB (Svjatogor).

At 0.01% exceedance probability, rain attenuation obtained from SAM model is 3.79 dB which is the closest to the locally measured rain attenuation (4.01 dB) compared to other models. This is probably as a result of the wide validity range in terms of elevation angle and frequency used. The rainfall database used to establish the models were obtained from the temperate climate. It is observed that most of these models used a fixed rain height and reduction factor respectively for estimating the slant path specific attenuation, which could have resulted in the improper evaluation of attenuation due to rain for this location. The estimation of rain height varies yearly as a result of variation in rainfall rate. Also new specific attenuation coefficients for prediction of specific attenuation could be determined from measured data instead of the ones predicted by ITU-R.

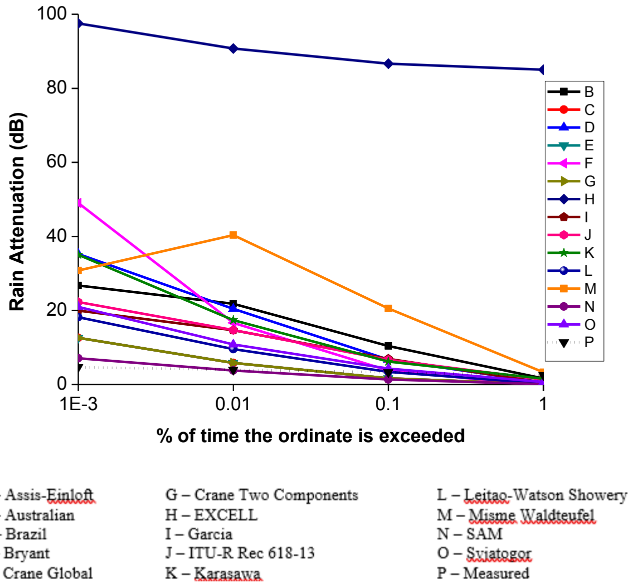

Figure 7 Comparison between measured rain attenuation and existing predicted rain attenuation models at CU, Ota

4. CONCLUSION

The measured average rain attenuation did not show good agreement with all the predicted models for the location except for SAM model that has its rain attenuation approximately very close to the experimental results of the measured rain attenuation. The attenuation predicted by the SAM model shows a very close correlation with the ground measured attenuation values. This model can be used in the location of interest but would require that the coefficients of this model be modified.

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