

Characteristics of rain fade slopes on microwave communication in Mowe, Nigeria

Abstract. In this paper, the rain fade characteristics at Ka (30 GHz) frequency band in Mowe (Lat 6.80° N, Lon 3.40° E) Nigeria have been presented. The analysis includes the first-order statistics of rain rate and rain attenuation and the second-order statistics of fade duration and fades slope for planning the frequently used point-to-point microwave link for various communication sector feeder networks in the study location. The fade duration and the fade slope were also carefully derived and subsequently compared with the ITU-R model. The results of this study would be a good tool for improving rain fade mitigation techniques in Nigeria.

1. Introduction

Satellite communication services using frequencies higher than 10 GHz have been steadily increasing due to the rapid growth of telecommunication networks. Unfortunately, attenuation caused by precipitation has the most common detrimental effect on satellite communication links at these frequency bands, particularly in the tropical and equatorial regions.

Frequency bandwidths large enough to carry such high data rates are not allocated in conventional frequency bands ranging from C-band to Ku-band in fixed satellite services. Only higher frequency bands provide such large bandwidths among are the Ka-band (20–30 GHz), Q/V-band (40–50 GHz), or EHF-band (20–45 GHz) [1]. Due to the degradation caused by rain on satellite radio links, the impact of fades cannot be overstated as satellite system designers look more into Ka-band frequency links and small, low margin earth terminals [2]. To mitigate the extreme fades in these frequency bands, fading dynamics are critical in designing adaptive coding or power control systems. A detailed understanding of dynamic fade characteristics is needed to parameterise fade mitigation techniques properly. Rain intensity, the number of events exceeding different attenuation thresholds, rate of change of attenuation, and fade slope are all dynamic properties of precipitation attenuation. This knowledge is crucial for device designers [3].

Many reports on fade slope have been conducted in recent years. However, these experiments were mainly in temperate climates [4]-[8]. Nelson and Stutzman [9] used the Olympus satellite beacons to study rain fade dynamics, including fade slope statistics, for a year of atmospheric propagation data collected and analysed in Blacksburg, USA. For a fixed occurrence standard, their calculated findings showed that fade slope increases with frequency. They also discovered that as attenuation levels rise, the frequency of broad fade slope magnitudes rises. Rucker [10] shares the same finding. Van de Kamp [4] used the previous findings to develop a new model adopted by the International Telecommunication Union (ITU-R).

In this paper, we estimated rain fades slope statistics using rain data collected in Mowe, Nigeria. The research will enable one to estimate effective transmission connections with minimal or no signal fluctuation over a typical year.

2. The study area

The rainfall data for this study were obtained from the Tropospheric Observatory Data Acquisition Network (TRODAN), a project of the National Space Research and Development Agency (NARSDA) under the Centre for Atmospheric Research (CAR), Anyigba, Kogi State, Nigeria. It is an Automatic Weather Stations Network, which was deployed across Nigeria. This equipment monitors the lower atmosphere, which covers the region from the Earth's surface to an altitude of about 11 km and carries out simultaneous measurements of meteorological and climatological variables, in real-time, through telemetry technology, with five minutes update cycles.

This study's experimental site is the Department of Physical Sciences at the Redeemer's University campus in Mowe, Ogun State. The details of the measurement site were described in Table 1. The data used in this analysis is based on rainfall measurements for twelve months in the year 2011.

Table 1. Characteristics of the study location

Station	Latitude (°N)	Rain rate ($R_{0.01}$)	Elevation angle (θ)	Height above sea level (mm)	Average annual rainfall (mm/year)	Observation period
Mowe	6.81	74.83	50.5	19.00	430.5	12 months (Jan. 2011-Dec. 2011)

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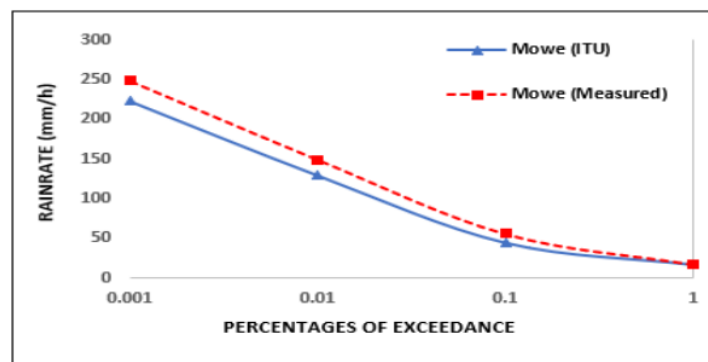
3. Results and Analysis

3.1. Rain rate distribution

Figure 1 describes the cumulative distribution of the rain rate. The measured rain rate was compared to the ITU-R P.837-5 [11]. The slope is steeper for the lower rain rates, as can be seen in the graph. The observation suggests that the lesser rain rate level contributes the most to overall rainfall. As rain intensity increases, the percentage of time recorded decreases, while as rain intensity decreases, vice versa. The $R_{0.01}$ is 135 mm/h and 156 mm/h for Measured and ITU-R, respectively, while $R_{0.1}$ is 54 mm/h and 68 mm/h for Measured and ITU-R. When compared the measured rain rate to the ITU-R P.837-5 forecast, it was found that the ITU-R underestimated the measured values by ~10%.

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The degree of conformity was found up to a time percentage of 0.3 per cent. After that, as the rain rate rises, there is a significant deviation between the measured rain rate and the ITU-R recommendation as the rain rate rises.



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Figure 1. Comparison of the cumulative distribution of rain rate.

3.2. Rain Attenuation Statistics

The downlink of microwave satellite communication system is almost entirely affected by high attenuation effects in tropical regions such as Nigeria, primarily when operating at high-frequency bands like the Ka (30 GHz) band. As a result, many scientists have concentrated their efforts on forecasting the impact of rain attenuation [12]-[14].

Rain-induced attenuation predictions in Figure 2 shows the results of the cumulative distributions of the predicted rain attenuation at Ka-band frequency for the NigComSat-1R elevation angle of 42.5° using the ITU-R 618-9 model [15]. 30 GHz (within the Ka-band downlink/uplink frequencies) was considered to address some of the issues posed by the rapid growth of satellite broadband networks. The results show that at 0.1 per cent of the time, the predicted rain attenuation for Ka-band downlink/uplink frequencies was 20 dB; at 0.01 per cent of the time, the rain attenuation exceeded 56 dB for downlink/uplink frequencies, and at 0.001 per cent, the rain attenuation predicted 97 dB.

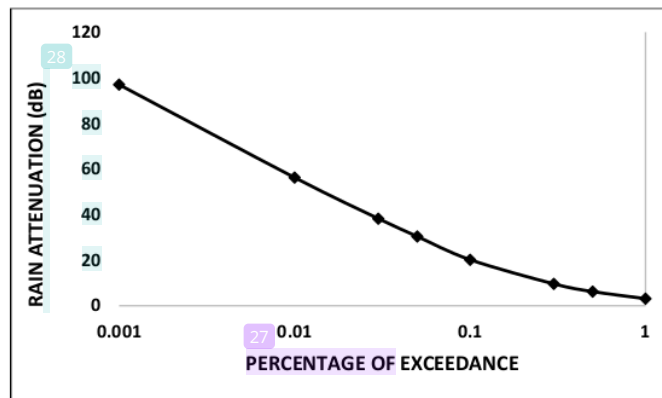


Figure 2. Cumulative distribution of rain attenuation.

3.3. Fade duration

Fade duration is the amount of time it takes for attenuation to reach a particular threshold value. The ITU-R P.16231 model [16] can be used to measure two different fade period distributions. The first is the NA(D), which is the number of fade events that are longer than a given D and exceed a given attenuation threshold A, expressed as a percentage of the total time the same attenuation threshold A is exceeded, regardless of interval length. This calculation can be used to estimate a machine outage. Device designers may use this information to incorporate effective fade countermeasures. The other distribution is the percentage of times an attenuation threshold A is exceeded with intervals more extended than a specified time.

Fade period statistics for attenuation levels greater than 1, 2, 5, 9, 14, 21, and 34 dB have been estimated and plotted in Figure 3. The number of activities during which the duration exceeds the abscissa at the specified level is shown. The length of fade events decreases as the attenuation threshold increases, as observed in Figure 3. At a 1 dB attenuation threshold, 4136 events were

recorded for a 10 s fade, while 1502, 602 and 151 events were recorded for 14 dB, 21 dB, and 34 dB, respectively [17].

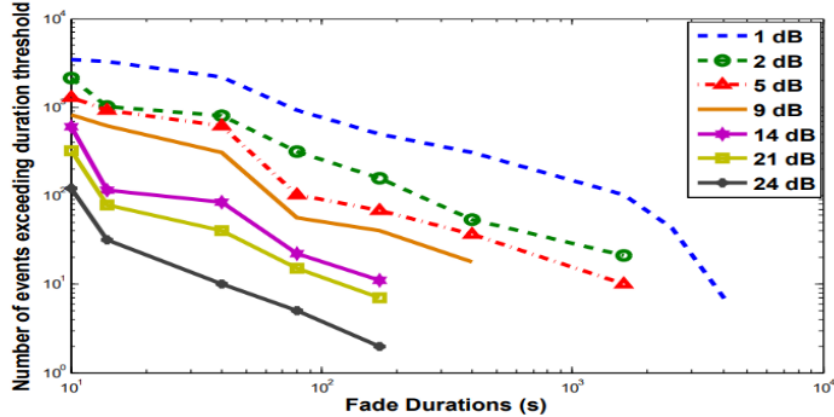


Figure 3. Cumulative distribution of fade duration by attenuation levels.

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3.4. Fade Slope

The fade slope indicates the rate of change in rain attenuation. Understanding the fade slope of attenuation caused by rain or other meteorological events is critical for fade mitigation strategies. This parameter must be understood to determine the appropriate tracking speed for fade mitigation techniques [18]. The International Telecommunication Union (ITU) proposed the ITU-R model in 2003 to quantify the statistics of fade slope due to rain attenuation on Earth-space paths [16]. The fade slope probability distribution was discovered to be dependent on climatic parameters. The fade slope (ζ) at a given point in time in the ITU-R model is defined as:

$$\xi(i) = \frac{A(i+0.5\Delta t) - A(i-0.5\Delta t)}{\Delta t} \text{ (dB/s)} \quad (1)$$

This model works for frequencies ranging from 10 GHz to 30 GHz and elevation angles ranging from 10 to 50°. The model needs the following parameters as input: where A is the attenuation level (dB) varying from 0 to 20 dB, f_c is 3 dB cut-off frequency of the low pass filter (Hz) ranging from 0.001 to 1 Hz, and Δt is the duration of the time interval over which the fading slope is calculated varies from 2 to 200 s. The measured data were used to estimate the conditional probability density function (CPDF) of the fade slope distribution. The conditional distributions at attenuation level A (dB) are defined by equation (2)

$$A - 0.5 < (t) \leq A + 0.5 \quad (2)$$

where A= 1, 2, 3, 4, ... dB. For example, the 2 dB distribution is obtained considering all fade slopes calculated for attenuation A(t) between 1.5 dB and 2.5 dB [8],[19].

Figure 4 shows the CPDF at selected attenuation levels of 1, 2, 4, 6, and 10 for the microwave links operating at 30 GHz. The figure that the fade slope data are distributed and symmetric around 0 dB/s. In addition, these distributions spread further as the attenuation level increases. With an increasing threshold value, the peaks are decreasing.

In Figure 5, the ITU-R model for rain fade slope is compared with the corresponding measured distributions for 2 dB and 10 dB. It was observed that the ITU-R model fits the measured data only

for certain attenuation levels and overestimates the CPDF. For example, at 2 dB, the peak of the CPDF for ITU R is 19 dB/s while it is 8.43 dB/s for measured, and at 10 dB, it is 11.0 dB/s and 5.5 dB/s for ITU-R and measured, respectively.

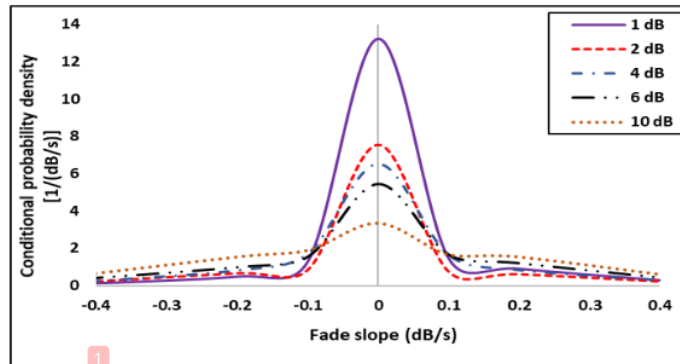


Figure 4. Distribution of measured fade slope data for selected attenuation values at 30 GHz.

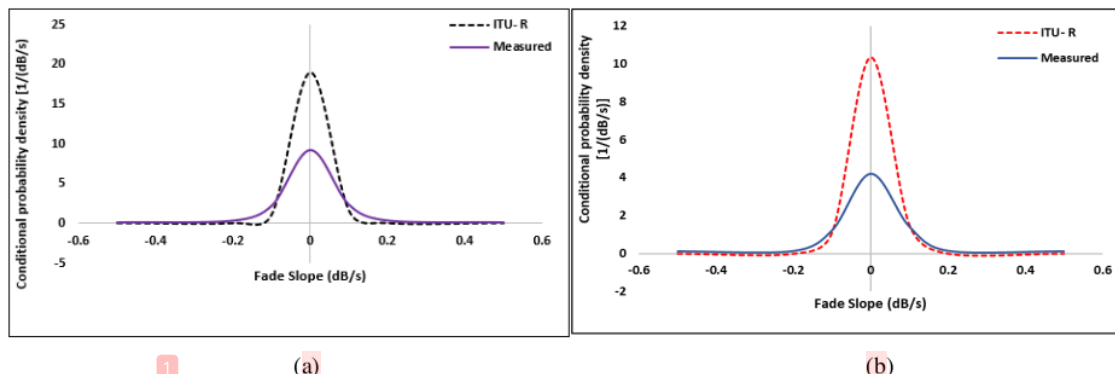


Figure 5. The CPDF of the measured fade slope data at Ka (30 GHz) band with the predicted ITU-R model for selected attenuation levels at (a) 2 dB and (b) 10 dB.

4. Conclusions

The findings of a propagation measurement operation conducted in Nigeria's tropical region (Mowe) are presented in this paper. The rain rate, rain attenuation CCDF, fade length and fade slope have all been analysed as main first and second-order statistics. This finding suggests that ITU-R rain attenuation prediction models in heavy rain regions, such as Nigeria, are more likely to underestimate measured rain attenuation statistics. For the fade slope, all the CPDFs follow a normal distribution with zero average. Also, the distribution becomes broader when the attenuation level and the magnitude of the fade slope increase with the attenuation level. Unlike the ITU-R earth-to-satellite rain fade slope model for earth-to-satellite links, it was found that the measured fade slope distribution at 30 GHz is better approximated by a normal distribution with mean equals to zero; however, the data decrease. It is therefore recommended that the ITU-R model should be modified for application in the tropical region.

The expected fade slope distributions presented here provide a starting point for developing fade mitigation systems.

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