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

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

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Abstract. In this paper, the rain fade characteristics at Ka-band (30 GHz) in Mowe (Lat 6.80º N, Lon 3.40º E) Nigeria have been presented. The analysis includes both the first- and second-order statistics of rain rate and rain attenuation, and fade duration and fade slope, respectively. Both parameters are useful for planning the point-to-point microwave link for various communication feeder networks. The estimated fade duration and the fade slope were compared with the ITU-R P.837-5 model. The results of this study would be valuable 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. In fixed satellite services, wide frequency bandwidths for transmission of high data rate are not available in the congested C- and Ku-bands. Higher frequencies that provide such large bandwidths are the Ka-, Q/V- and EHF-bands [1]. The impact of fades as a result of degradation caused by rain on satellite radio links cannot be overemphasised as more attention is being paid to Ka-band and low-fade margin earth-space links [2]. In order to mitigate these extreme fades, measures such as adaptive coding and power control techniques are used to improve fade dynamics. A detailed understanding of dynamic fade characteristics is needed to parameterise link's fade mitigation techniques (FMTs) properly. The rain intensity, the number of events exceeding different attenuation thresholds, fade duration, and fade slope are all properties of fade dynamics. These parameters are crucial to device designers [3].

Many experiments 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 the dynamics of rain fade using data analysed in Blacksburg, USA. For a fixed occurrence standard, their calculated findings showed the frequency dependence of fade. They also discovered that as attenuation levels rise, the frequency of broad fade slope magnitudes rises. Rücker [10] shares the same finding. Van de Kamp [4] used the previous findings to develop a new model recommended by the International Telecommunication Union (ITU).

In this paper, rain fades slope statistics were estimated using rain data collected in Mowe, Nigeria. The research will enable the estimation of effective transmission parameters with minimal or no signal fluctuation over a typical year.

2. The study area

Tropospheric Data Acquisition Network (TRODAN) rainfall data were used for this study. TRODAN is an automatic weather stations network deployed across Nigeria by the National Space Research and Development Agency (NASRDA). This equipment monitors the lower atmosphere with five minutes data resolution. The rain gauge is located in the meteorological garden of the Department of Physical Sciences, Redeemer's University, Mowe, Ogun State. The details of the measurement site were described in Table 1. Twelve months of rainfall measurements (2011) were used for this study.

Table 1. Site parameters

Station	Latitude (°N)	Longitude (°E)	Rain rate ($R_{0.01}$)	Elevation angle (θ)	Height above sea level (mm)	Average annual rainfall (mm/year)	Observation period
Mowe	6.81	3.43	74.83	50.5	19.00	430.5	12 months (Jan. 2011-Dec. 2011)

3. Results

3.1. Distribution of Rain rate

The plot of rain rate at different percentages of exceedance obtained from the analysis compared with that of the ITU- R model [11] is shown in Figure 1. At lower percentages of exceedance, the slope is steeper than at higher values. As rain intensity increases, the time percentages of exceedance is observed to decrease and 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. From the foregoing, the model overestimated the measurement by about 10%.

The degree of conformity was found up to a time percentage of 0.3 percent. Thereafter, as the rain intensity rises, there is a marked deviation of the model from the observed values.

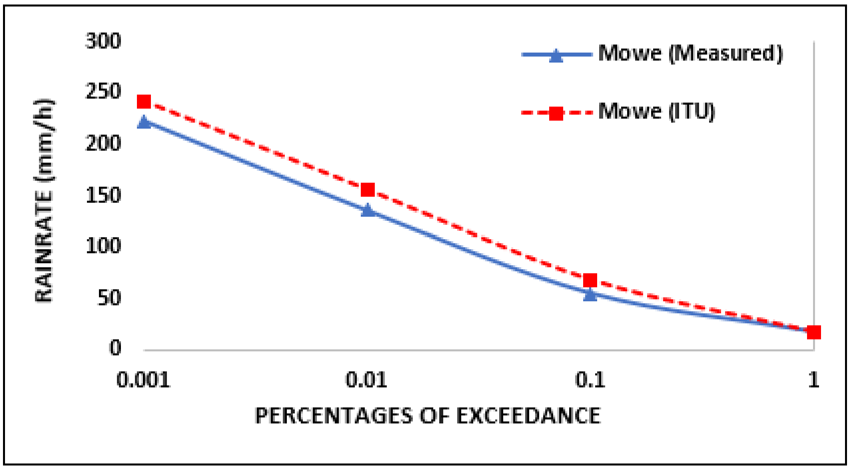


Figure 1. Comparison of the observed rain rate with ITU-R model.

3.2. Rain Attenuation Statistics

In tropical regions such as Nigeria, satellite downlinks are susceptible to elevated attenuation, primarily when operating at high-frequency bands like the Ka-band (30 GHz). As a result, many scientists have concentrated their efforts on forecasting the impact of rain attenuation [12]-[14].

Figure 2 depicts the attenuation as a function of percentage of exceedance obtained for the Ka-band channel of NigComSat-1R, at an elevation of 42.5°, using the ITU-R 618-9 model [15]. 30 GHz was deemed applicable to address some of the emerging trends observed in the demand for satellite broadband. The results show that at 0.1 percent of the time, the predicted attenuation for Ka-band downlink/uplink frequencies was 20 dB; at 0.01 it exceeded 56 dB for downlink/uplink frequencies, and at 0.001, the rain attenuation predicted 97 dB.

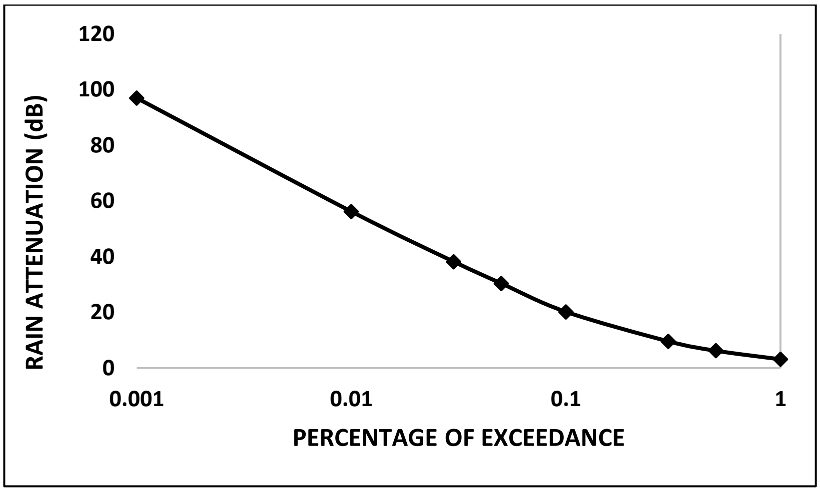


Figure 2. Cumulative distribution of rain attenuation.

3.3. Fade duration

This 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 counts longer than a given mean duration time, D, of fade duration and exceed a particular attenuation level, A, regardless of interval length. The calculation can be applied to estimate a machine outage. Device designers may use this information to incorporate effective FMTs. The second distribution is the percentage of the times an attenuation level A is exceeded with intervals longer 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 surpasses the percentage of exceedance axis at the specified level is shown in the figure. As observed in Figure 3, the length of fade events diminishes with increase in attenuation threshold. 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].

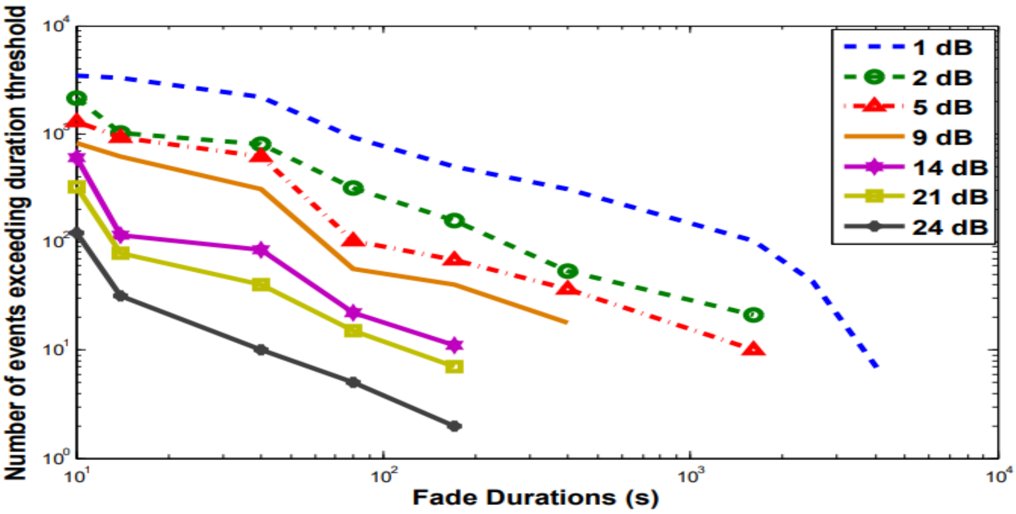


Figure 3. Cumulative distribution of fade duration by attenuation levels.

3.4. Fade Slope Estimation

This is defined as the rate of change in rain attenuation. Understanding fade slope is critical to FMT. This parameter must be understood to determine the appropriate tracking speed for FMTs [18]. The ITU proposed model (2003) quantifies the estimation of fade slope on Earth-space links [16]. The probability distribution of fade slope was over times observed to be dependent on link frequency, elevation angle and attenuation. The fade slope, ζ (dB/s), at a given point in time in the ITU-R model, is defined as:

$$\boldsymbol{\xi\ (i) = \frac{A(i+0.5\Delta t)-A(i-0.5\Delta t)}{\Delta t}} \tag{1}$$

This model is applicable to 10 – 30 GHz frequency range, and 10° – 50° angles of elevation. This model requires the following parameters: 0.001 – 1 Hz low-pass filter 3 dB cut-off frequency, f_c, 0 – 20 dB attenuation level, A, and the fade slope duration, Δt. Δt varies from 2 to 200 s. The measured data were used to estimate the conditional probability density function (CPDF), given by equation (2)

$$A - 0.5 < (t) \leq A + 0.5 \tag{2}$$

where A = 1, 2, 3, 4, … dB [8],[19].

Figure 4 illustrates the CPDF at different attenuation thresholds, 1, 2, 4, 6, and 10 dB at 30 GHz. It was observed in Figures 4 and 5 that at each of the attenuation threshold, the CPDF values increase with increase in the values of the fade slope (from negative values), reaching their maximum values at 0 dB/s, thereafter, the CPDF values decrease with increase in fade slope values. This is reflected on the curve having its peak at zero. In other words, the fade slope data showed leptokurtic normal distribution. With an increasing threshold value, the peaks are seen to be decreasing.

Figure 5 compares the fade slope model with the observed distribution for 2 dB and 10 dB. The ITU-R model agrees with the measured data at specific thresholds while overestimating the CPDF at other levels. For example, at 2 dB, the peak of the CPDF for ITU R is 19 dB/s while 8.43 dB/s for the measured, and at 10 dB, it is 11.0 dB/s and 5.5 dB/s for ITU-R and measured, respectively.

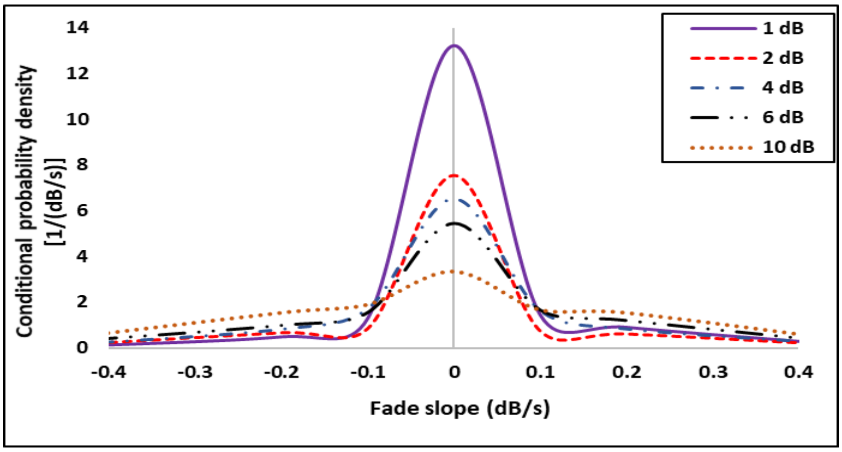
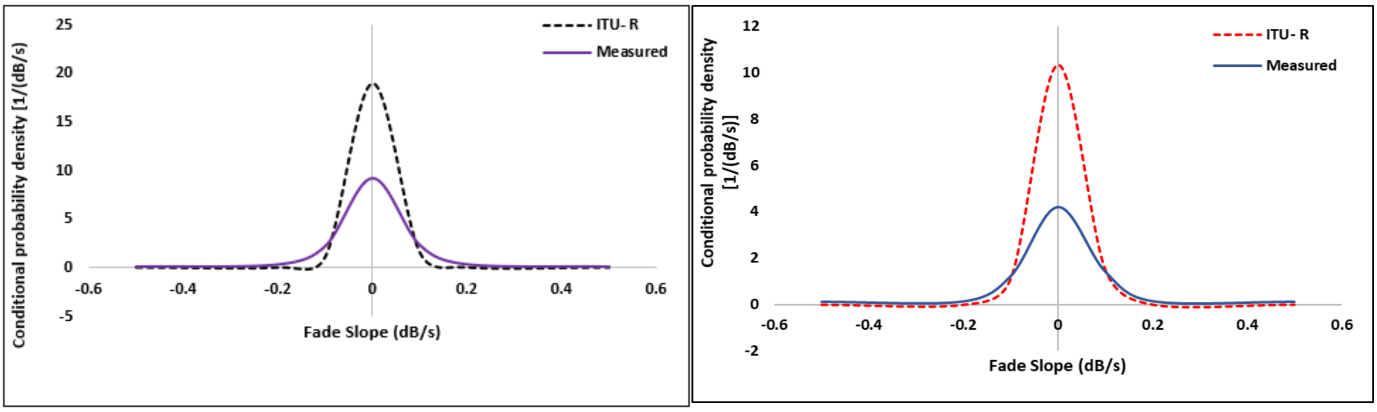


Figure 4. Distribution of observed fade slope data at specific attenuation for 30 GHz.



(a) (b)

Figure 5. The observed and the ITU-R CPDFs compared at (a) 2 dB and (b) 10 dB.

4. Conclusions

The findings of a propagation measurement conducted at Mowe, Nigeria, a tropical region are presented in this paper. The rain rate, rain attenuation, fade interval and fade slope have all been analysed as the main first- and second-order statistics. These findings suggest that ITU-R rain attenuation prediction models in heavy-rain regions, e.g., Nigeria, are more likely to overestimate measured rain attenuation statistics. For the fade slope, all the CPDFs are normally distributed. Also, the kurtosis of the distributions is attenuation and fade slope dependent. The results of this study suggest that a recommendation be made for the modification of the ITU-R model to fit climatic characteristics of the tropical region.

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