Review of Rain Attenuation Measurements on Earth – Space Links in Nigeria

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***Abstract*—Due to the prevailing impact of rain on microwave and millimetre wave propagation in tropical climates, fade margins derived from experimental campaigns would provide more practical estimates for planning. In this paper, the extent of work done on the experimental assessment of the attenuation induced by rain on practical earth-space links in Nigeria is presented. The cumulative rain rate distributions derived from the instantaneous precipitation indices for propagation modelling and the estimation of fade margin is presented for Ile-Ife, Akure, Ilorin, Ota, Osogbo and Ogbomoso. Results reveals the spatial variability of the point rainfall rate across these stations. Although the stations engaged with measurement on rain attenuation are limited in number, preliminary results from new stations are presented, while addition data from ongoing campaigns will provide a robust indices for modelling the digital DTH links and for evaluating the performance of pre-existing models over Nigeria.**

Keywords-rain attenuation; earth-space links; cumulative rain rate; DTH links

I. INTRODUCTION

Due to the short wavelength available for transmission on terrestrial and earth-space microwave and millimetre wave links, the attenuation of communication signals is high and the effect on the quality of the service delivered is pronounced at frequencies beyond 10GHz [1]. The situation is intense in the tropical regions, which includes Nigeria and this is mostly attributable to the high rainfall intensity and large rainfall size characterizing rainfall events in the tropics.

Seemingly, the impact of such natural phenomena has been successfully observed over the years. Such observations are reliable for the modelling of the performance of communication systems and the design of appropriate mitigation techniques for surmounting these problems. Interestingly, a number of rain attenuation models exist and have been useful for link planning. However, most of those available were developed from observations in the temperate regions and they are often adopted for planning in the tropics. Literally, these global models are largely patronized because of the limited experimental observations in the tropics.

Apart from the expected year-to-year estimates by existing attenuation models, these models also provide station-to-station variation at the same exceedance probability [1]. Hence accurate estimation of fade margins for planning reliable space-earth and terrestrial links depend to a large extent on estimates obtained experimentally at specific locations. In the absence of such experimental attenuation estimates, accurate fade margins could also be estimated using a suitable model with the knowledge of local precipitation data.

Several experimental efforts have provided practical estimates over tropical Malaysian climate [2-6], tropical Singaporean climate [7, 8] and over the equatorial South African climate [9, 10] etc. Experimental observation over Nigeria is still exceptionally limited and this remains a major concern to radio scientists and engineers.

TABLE 1: LOCATIONS WITH PRECIPITATION MEASUREMENTS FOR RADIO-CLIMATIC APPLICATIONS

Location	Latitude (^{0} N)	Longitude (^{0} E)	Altitude (m)	ITU-R rain climatic zone	Observation period
Ile-Ife	7.33	4.34	274	P	1979 – 1981
Ilorin	8.30	4.32	399	N	1989 – 1992
Akure	7.17	5.18	358	P	2012 – 2014
Ota	6.7	3.23	74	P	2013 – 2014
Osogbo	7.42	4.31	229	P	2013 – 2014
Ogbomoso	8.15	4.25	323	P	2009 - 2010

For instance, the first ground based attenuation measurement in Nigeria commenced at Ile-Ife on the 1st of July, 1987 by McCarthy, et al. [11]. Since then no such measurement was conducted until most recently, where a number of attenuation measurements are set up to quantify the effect of precipitation on present-day applications such as digital television. The rain attenuation measurement network comprise of the installations at the Federal University of Technology, Akure, Ondo state; Osun State University, Osogbo, Osun State, Nigeria and Covenant University, Ota, Ogun State. The purpose of this paper is to review what was done and their findings so far.

II. IN-SITU PRECIPITATION MEASUREMENTS FOR RADIOWAVE PROPAGATION IN NIGERIA

The collection of rain rate data started in Ile-Ife, Southwest Nigeria in September 1979 with the use of a fast response rain gauge and a tipping bucket rain gauge as backup [12]. Data obtained from this experimental work was useful for the investigation of the effect of integration time on the rain rate and the deduction of equivalent cumulative rain rate distribution. A similar measurement was conducted as presented in [13] for Ilorin and Ile-Ife. In their work, different characteristics of the effects of rain on the propagation of radio waves were presented. Results show significant variation between the measured and those predicted by ITU-R. [14]. Other recent precipitation measurement campaigns are currently running at locations detailed in Table 1.

A. Rain Rate Conversion

As a result of the rapidly varying nature of rainfall at a given point, the measured cumulative rainfall rate distribution is reliant on the sampling time of the rain gauge. Rain gauges with short integration time account for fluctuations on the link and are recommended for radio-climatic applications. Practically, those calibrated to log the precipitation data instantaneously at 1-minute or lower time intervals are often used. However, with the increasing number of weather stations across Nigeria, the dearth of rainfall data of low integration time is still eminent. Observations from the national weather bureau are predominantly in longer sampling time, typically presented as daily accumulations.

Ajayi and Ofoche [12] earlier developed a table for converting rain rates available in other integration time to the 1-minute equivalent. The data obtained from the fast response rain gauge with an integration time of 10s was used to show the empirical relationship between rain rate statistics with different integration time. The results obtained between 1-minute and 5-minute integration time were compared with those obtained by Flavin [15]. In their work, some other statistical properties of tropical rainfall were deduced and this includes the duration characteristics for various rain rates. The relationship is as given in equation (1), where R is the rain rate, τ is the integration time at which the rain rate is required and T is the integration time at which the rain rate is available.

TABLE 2: POWER LAW ESTIMATES FOR LOCATIONS IN SOUTH-WESTERN NIGERIA

Location	Ile-Ife	Ogbomoso	Akure
Power law estimates	$R_1 = 0.991R_5^{1.098}$	$R_1 = 0.797R_5^{1.195}$	$R_1 = 0.749R_5^{1.380}$

$$R_\tau = aR_T^b \quad (1)$$

Similar approach was employed in [16, 17] for obtaining coefficients a and b for Ogbomosho and Akure – other tropical locations in South Western Nigeria. In their work, equivalent 1-minute statistics were deduced based on observations from electronic weather stations at the respective locations. The coefficients derived from such efforts in the South West Nigeria is as presented in Table 2 for conversion from 5-minute to 1-minute rain rate statistics.

Considering the behaviour of C_e, the ratio of the exceedances for a given rain rate R measured for rain gauges with integration time T and C_R, the ratio of rain rates exceeded for a given percentage of time as measured by rain gauges with integration time T and τ were obtained. Across these three sites namely; Ile-Ife, Ogbomoso and Akure, C_e for $T\ (5 - minute)$ and $\tau = 1 - minute$ were obtained and it is evident that it decreased rapidly with increase in rain rate. The variation across the locations also show that C_e depends on the climate, which is in disagreement with Watson et al. [14], that it is a global constant. While on the average, the percentage difference between the C_R values obtained in the temperate region and at the tropical station increases with increasing integration time but, the C_R obtained for the integration time of 10s at Ile-Ife was seen to be lower than the values for the European stations.

The rain rate duration is equally important for the study of the characteristics of precipitation and the duration of the fade. It also provides information concerning cell sizes if the speed of the rain cell is known. The duration of increased rain is a useful piece of information for the estimation of expected outage due to rainfall attenuation on a radio link. The number of occasions when specified rainfall rate was continuously exceeded for duration of Δt seconds was obtained using the power law relation:

$$N(R) = \alpha(\Delta t)^\beta \quad (2)$$

where α and β are functions of rain rate and they are given as $\alpha = 3720 = 22.8R$, while $\beta = 0.82exp(0.004R)$.

It is apparent from results presented in Table 2 that the coefficients derived actually vary from one location to another. Although the reason for the bias might be as a result of the varying sensitivity of the rain gauges used, it is not out of place to also infer that the coefficients are location specific [17].

TABLE 3: CHARACTERISTICS OF THE MEASUREMENT STATIONS

Site	Latitude (^{0} N)	Longitude (^{0} E)	Altitude (m)	Elevation angle	Average annual rain accumulation (mm)
Ile-Ife	7.33	4.34	274	48.3^0	1400
Akure	7.17	5.18	358	52.3^0	1314
Osogbo	7.42	4.31	229	52.5^0	1245
Ota	6.7	3.23	74	59.9^0	1121

III. RAIN ATTENUATION MEASUREMENTS ON EARTH-SPACE LINKS IN NIGERIA

High rainfall rates occurring for long periods of time could lead to unacceptable outages on radio links operating in the microwave and millimetre wave bands. Significant efforts have been documented on the prediction of rain attenuation over Nigeria. Such predictions are made based on the available microphysical parameters for rain over a particular location. However, due to the dearth of such local precipitation data with a balanced spatial distribution across Nigeria, recent approaches [18, 19] have been based on the use of archival meteorological data using a hybrid of long term surface accumulation of rain and those from satellites such as the Tropical Rain Measurement Mission (TRMM) satellite, the Atmospheric Infrared Sounder (AIRS) satellite (from NASA, USA) and GTOPO30 (USA). Although the attenuation estimates and contours deduced still remain useful tools for planning satellite and terrestrial microwave links over Nigeria, there is the need to experimentally evaluate the performance of the microwave and millimetre wave links using instantaneous precipitation measurements. This is vital, especially now that the deployment of digital television, broadband services and a number of other applications increasingly demands for the use of these bands.

Earlier experimental efforts include [11, 20], where the attenuation induced by rain was observed on a $11.6\,GHz$ Dicke-switched radiometer, with a $1.8m$ front-fed antenna collocated with a tipping bucket rain gauge at Ile-Ife ($4.34^oE, 7.33^oN$). The 2 years data was analysed at INTELSAT and the path attenuation was derived over a physical medium with a temperature of $285K$ and a H factor of 0.9.

However, observations in Akure [21, 22], Osogbo and Ota provide more recent results on the performance of a practical DTH link during high rainfall events. These current installations were setup based on the concurrent measurement of the rainfall intensity and the received signal level. For observations at 12.245 GHz using a 0.9 m offset parabolic reflector across these stations, the received signal level is sampled and logged every 60 seconds using a spectrum analyser, which is connected to personal computers. Other vital characteristics of these earth stations are presented in Table 3.

The reception of digital television contents at Akure, Osogbo and Ota is premised on the practical DTH links established via selected Ku band transponders on EUTELSAT W4/W7, which is located at longitude 36^0 East.

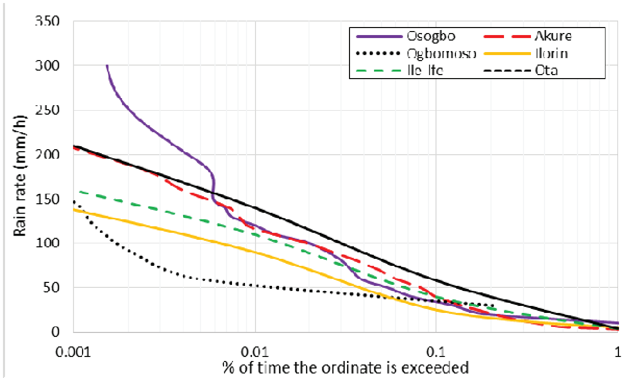
The data obtained from the new stations are sorted into daily and monthly observations. Rainfall events are identified from the precipitation data, and the received signal level correspondingly separated. The experimental data is therefore categorized into clear air and rainy events and the attenuation induced by rain is estimated using;

$$A_R = RSL_{CS} - RSL_R \qquad (3)$$

where RSL_{CS} is the reference level obtained by averaging the received signal level during clear air, while RSL_R is the received signal level any other instance of time.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

The cumulative rain rate distributions derived from the instantaneous precipitation indices for propagation modelling and the estimation of fade margin is presented in



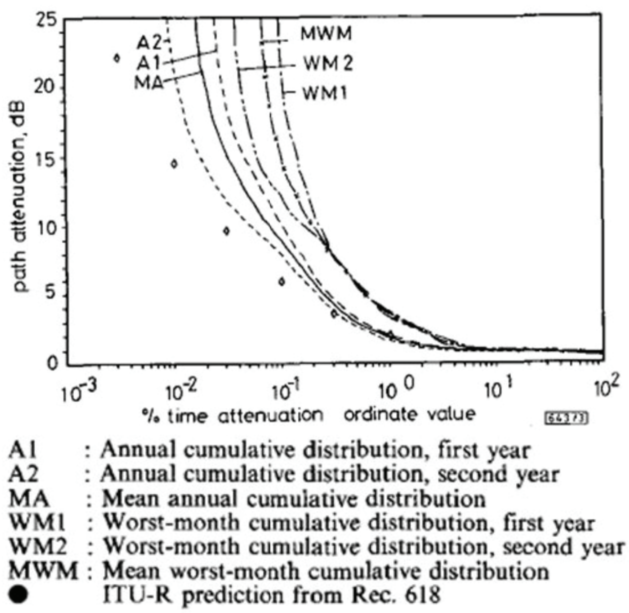


Figure 2: Cumulative distribution of the path attenuation observed at Obafemi Awolowo University, Ile-Ife [11]

Figure 1 for Ile-Ife, Akure, Ilorin, Ota, Osogbo and Ogbomoso. Results reveals the spatial variability of the point rainfall rate across these stations. At Ile-Ife, the point rainfall rate of 110 mm/h was derived from the 2-year measurement, while 120 mm/h was exceeded for 0.01% of the time in Akure [23] and Osogbo [24]. The estimate derived from a 1-year measurement in Ota [25] however records the highest threshold of 140 mm/h rain rate exceeded at 0.01% of the time. For Ilorin [26], about 90 mm/h was recorded while 60 mm/h was recorded for Ogbomoso [16] and this appears to be the least from an in-situ measurement in this region.

On the results for rain attenuation on earth-space links, it was established in [11] that the ITU-R path attenuation procedure underestimates the derived attenuation significantly on this link. This is as presented in Figure 2 [11], while the initial results for the measurements at FUT, Akure and Covenant University, Ota is shown in Figures 3 [21] and 4. In Figure 3, the degrading effect of high rainfall intensity is shown in the time series for the rainfall intensity and the received signal level for the 6-month observation period. Results from detailed analysis in [22] reveals that the received signal squelches whenever the rainfall rate rises above 64 mm/h. At this level, the digital television content is completely lost to the prevailing rainfall intensity and is restored when the rainfall intensity drops significantly. The rain attenuation on the DTH setup at Covenant University, Ota is presented in the scatter plot in Figure 4, showing the

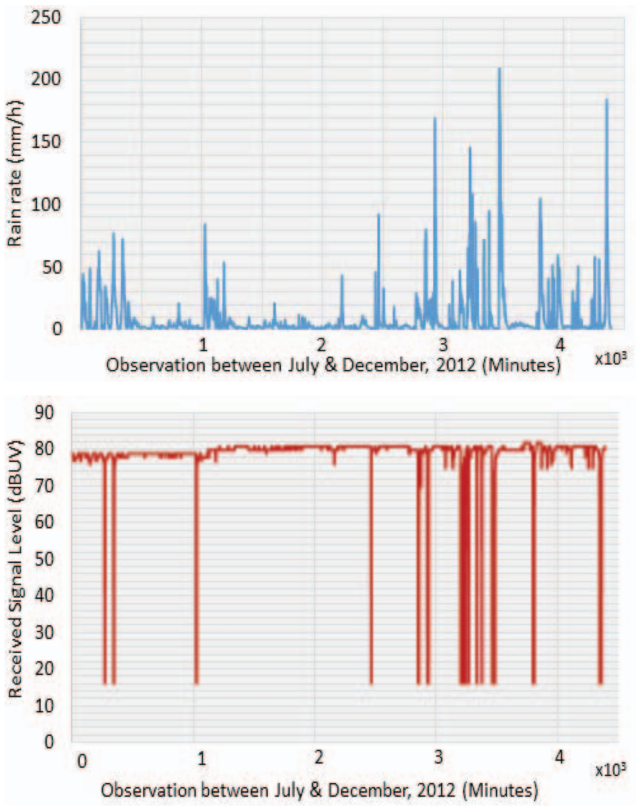


Figure 3: Preliminary results from the measurement at FUT, Akure

relationship between the fluctuations observed on the received signal due to the rainfall intensity. As shown in Figure 4, the linear and power law fit presents the empirical relationship between the received signal level and the rainfall intensity. However, a more distinct fit can be achieved with a robust data set from this measurement.

CONCLUSION

The extent of work done on the experimental assessment of the attenuation induced by rain on practical earth-space links has been presented. The variation observed in the point rainfall rate across the stations could be attributable to the obvious variation in the sensitivities of the equipment used (rain gauges). The results obtained for the rain attenuation at 11.6 GHz reveals that the ITU-R path attenuation procedure provides lower estimates than the measured ones, the performance of the global ITU-R has not been distinctly ascertained in other locations – for measurement at 12.245 GHz, and this is due to the limited rain attenuation data for most of these new stations. Although preliminary results have been presented, addition data from the measurements ongoing at the stations will provide a robust indices for modelling the digital DTH links and for evaluating the performance of pre-existing models over Nigeria.

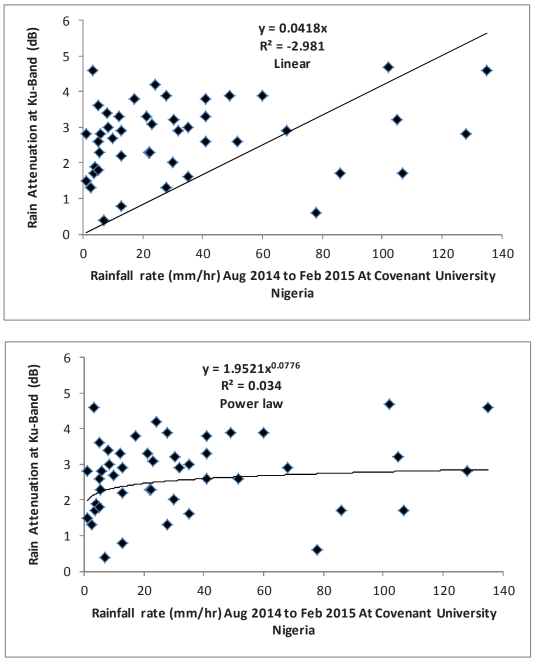


Figure 4: Preliminary rain attenuation estimates from the measurement at Covenant University

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