Dimensional Statistics of rainfall Signature and Fade Duration for Microwave Propagation in Nigeria

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Abstract

As the communication services are increasingly demanding more access for higher frequencies up to Ka-band and beyond, dimensional statistics of rainfall for predicting rain induced attenuation is required in order to estimate the link budget and the communication performance. Attenuation due to rain restricts the path length of radio communication systems and limits the usage of higher frequencies for terrestrial point-to-point microwave links and satellite communications. In this paper, some results of dimensional statistics of rainfall signature and fade duration are presented. Rain events are studied to examine the efficacy of predicting the slant-path attenuations from point rain rate measurements.
Keywords: Rainfall signature**,** Fade margin, Microwave propagation, Tropical region, automatic weather station.

1.0 Introduction.

The dynamics of rain-induced fades on satellite radio links can not be overemphasized as satellite system designers look more into Ku and Ka bands frequencies links and small, low margin, earth terminals. The dynamic of fading are important in the design of adaptive coding or power control systems to alleviate the severe fades which occur at these frequency bands. For example, the number of events exceeding different attenuation levels and the corresponding mean fade event duration are necessary hints to the system designers.

The current state of the telecommunication market is driven by the increasing demand of the end users for multimedia services, which require high data rates. Within the fixed satellite service, frequency bandwidths wide enough to carry such high data rates are not allocated in conventional frequency bands ranging from C-band to Ku-band. Such wide bandwidths are available only at higher frequency bands such as Ka-band (20–30 GHz), Q/V-band (40–50 GHz) or EHF-band (20–45 GHz). For the next generation of satellite telecommunication systems, different types of system architecture are envisaged for multimedia applications such as, for instance: broadband access star network with Ku/Ka-band transparent payloads and low-cost terminals for consumers, broadband access mesh network with Ku/Ka-band regenerative payloads and VSAT terminals for corporate, backbone core networks with Ka/Q/V-bands regenerative payloads for interconnection of gateways [1]. Hence, reliable rain-fade statistics are required at a number of locations throughout the world which will establish; the expected number of minutes-per-year rain-fades exceeding given levels of attenuation, characteristics of the time of the day and monthly fades since human activities are based on 24h cycles, diurnal variations, and year-to-year variations. Therefore, it has become paramount for radio engineers or network operators to predict the quality of service that will be provided to its customers. In order to do this, there must be good knowledge of the amount of time in a year that the service is available. Also, the investigation of rain-induced attenuation at such frequencies is made relevant not only because the amount of bandwidth available in the Ka and EHF bands enables the provision of complex multimedia applications, but also because of the current congestion that the Ku band is experiencing. This scenario makes higher- frequency bands more attractive for the deployment of new systems.

For the present study, rainfall measurements at Akure, south western Nigeria, have been analyzed. The study will enable one to predict the amount of time, during a typical year that a transmission link will operate efficiently with little or no fluctuation of signals. This will in turn be helpful to device suitable fade Mitigation techniques (FMT) such as time diversity and automatic repeat request over this region.

2.0 EXPERIMENTAL SET-UP

The experimental set-up includes a tipping bucket raingauge with 0.1 mm sensitivity and a data acquisition unit along with other sensors in unit form that measured the following parameters; soil moisture content (volume of water), wind speed and wind direction, air temperature, relative humidity among others. The rain water is collected in a

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standard funnel and is converted into drops of equal sizes. The number of drops collected every 10 seconds is counted electronically and averaged over 5 minutes. The AGC voltage of each channel is continuously sampled and stored in digital form, together with the date and time of each raingauge tip. The calibration of the raingauge is maintained by cleaning the capillary. The overall reliability of the gauge is extremely high due to the simple drop-forming mechanism. The reliability has to be ensured by keeping it clean, so that dust particles do not obstruct the free flow water.

The experimental site is located at the Department of Physics, the Federal University of Technology Akure, Nigeria. Table 1 shows the descriptions of the measurement site. The data considered in this study is based on rainfall measurements for a period of two years (August 2008 to August 2010) from micro rain radar and raingauge which are located in the department.

Table 1: Site characteristics of the study locations

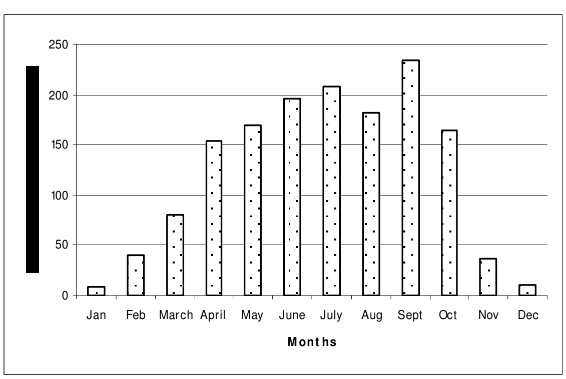
Station	Latitude (^{0} N)	Longitude (^{0} E)	Altitude (m)	Average Annual Rainfall (mm/year)	ITU-R Rain Zone	Highest monthly Precipitation (mm/month)	Region climate Rain gauge
Akure	7.17	5.18	358	1485.57	P	463.8	Rain forest zone

Since a 1-minute integration time has been accepted as suitable for attenuation prediction for frequencies greater than 10 GHz [2], the 5-minute rainfall data is converted to 1-minute integration data using the method of Lavergnant and Gole (LG) [3]. The model which was an improvement over the ITU model [4] is suitable for this kind of analysis because it has the advantage of converting both the probability of rain rate occurring in 5-minute integration time to probability of rain rate occurring in 1-minute as well as converting the equivalent rain rate of 5-minute to 1-minute [5]..

3.0 Distribution of Rain rate

Figure 2 shows the average monthly rainfall accumulations during the observation period. The average monthly rainfall depends on the effects of movement of the InterTropical Convergence Zone (ITCZ). In summer, the ITCZ discontinuity follows the sun northward, as a result, more and more of the country comes under the influence of the moisture–laden tropical maritime air. As summer wanes, the zone shifts southward, bringing an end to the rainy season. Nigeria has two seasons, dry (Nov., Dec., Jan., and. Feb) season and wet (the rest of the calendar year) season. Rainfall usually falls during the wet season and during this period the ITCZ moves across the country.

It could be observed that the region recorded its peak average monthly rainfall accumulation of 234 mm in the month of September. Due to ITCZ movement, rain continues to fall even during dry season in the rain forest regions. The cumulative distribution of rain rate is also presented in Figure 3. It could be noticed from the figure that the slope is steepest for the lower rain rate. This means that the lower rain rate class contributes most to the total rainfall; the higher the rain intensity the lower the corresponding percentage of time recorded, while the lower the rain intensity the



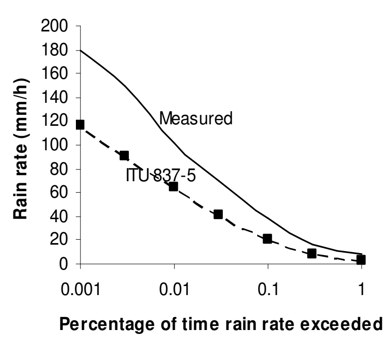


Fig. 2: Average monthly rainfall accumulations (mm). **Fig. 3:** Comparison of measured rain rate with ITU prediction

higher the percentage of time. The comparison with ITU 837-4 [6] prediction shows a deviation of about 38% from the measured values. Hence, the recent ITU rain rate model grossly underestimates rain rate over Nigeria and may, therefore, not be suitable for Nigeria.

Figure 5 presents the dynamical characterization of rain events over the region while figure 6 shows the scatter plot of average rain event intensity against rain event duration. It is of interest too to examine the dynamic characterization of the rainfall intensity events over the region. Amidst the data available, we try to discriminate the yearly intensities exceedance on the hour of the day (if possible) the calendar month. This will enable us to resolve which periods of the year contribute most to the small exceedance. Considering an average day for each exceedance selected, it could be observed that the impact of convective rain contributing mainly to the small percentages of time. We see for example that low values of rain rate are completely independent of the hour of occurrence whereas for very small percentages of time, values of rain rate in excess of about 120 mm/h are very dependent on the time of day. There exists also the particular feature that these very heavy rates are produced in the evening or early hours in the morning. The early hour of the day constitute the thick office/business hour, when most of the transaction is expected to be done. While, people are expected to relax and enjoy direct to home services in the evening time. There is also coefficient of correlation of about 0.12 as presented in figure 6. System analyst should take note of this variation bearing in mind the commercial activities of the region.

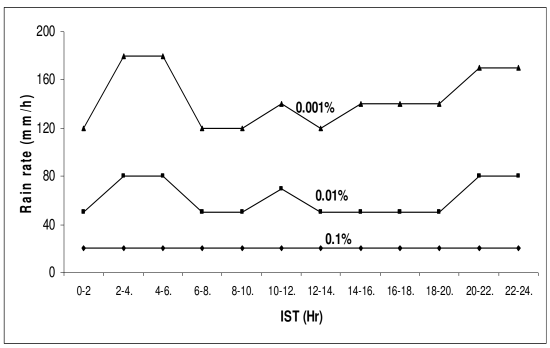


Fig. 5: Evolution of rain intensity throughout an average day for the indicated exceedance of time.

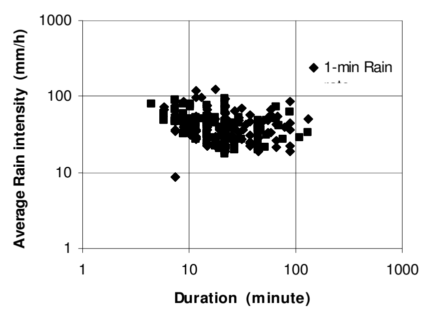
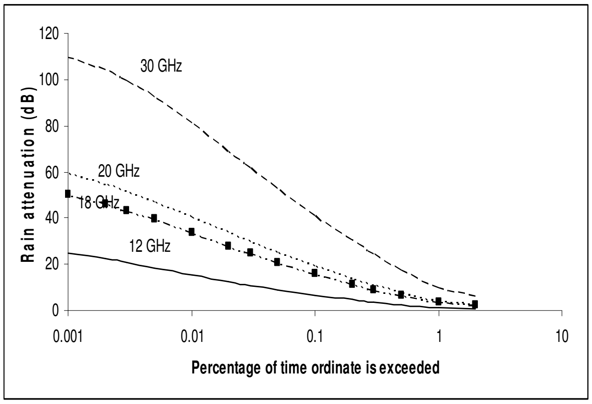


Fig. 6: Scatter plot of the dependence of average rain event intensity on rain event duration

4.0 Rain-induced Attenuation Predictions

Figure 7 shows the results of the cumulative distributions of the predicted rain attenuation at different frequencies (Ku- and Ka-band frequencies) over the NIGCOMSAT-1 elevation angle of 42.5^o using the ITU 618-9 model [7]. In order to meet today's active challenges in the rapid growth of satellite broadband networks, frequencies of 12 GHz and 14 GHz (within the Ku-band downlink/uplink frequencies) as well as frequencies 20 GHz and 30 GHz (within the Ka-band downlink/uplink frequencies) are considered. The result shows that at 0.1% of time, the rain attenuation predicted varies between 7 and 16 dB for downlink/uplink frequencies (12-18 GHz) of Ku band, while at the Ka-band downlink/uplink frequencies, the predicted rain attenuation varies between 19 and 61 dB.. Also at 0.01% of time, the rain attenuation exceeded varies between 15 and 34 dB for downlink/uplink frequencies of Ku band while at the Ka-band downlink/uplink frequencies, the rain attenuation varies between 34 and 116 dB.

Figure 8 present the log normal fit for the comparison of the 1-minute rain rate with rain-induced attenuation. The attenuation data were plotted assuming that the total time that attenuation occurred was the same as the time that it rained. There is a noticeable change in the attenuation data at 10 dB due to breakpoint. It has been reported that attenuation events having peak attenuations exceeding 10 dB were usually produced by thunderstorms, and these may be the cause of the steeper rise above 10 dB The results from the figure also show that at 0.2% of time and higher frequency of 30 dB, the value of rain attenuation intersects with that of rain rate and thereafter increases. This mean that at higher time percentage up to 0.2% for higher frequency of 30 GHz, the values of attenuation obtained is higher than the values of rain rate that produces it.



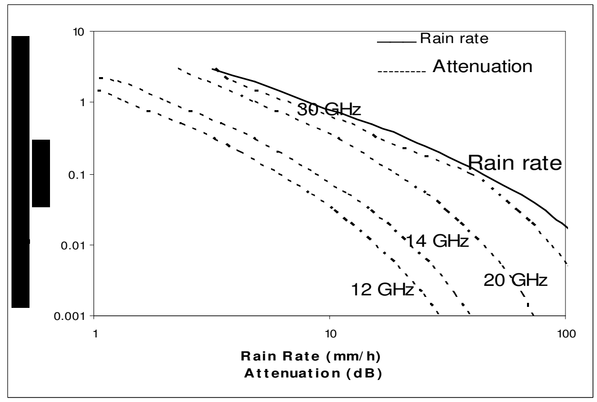


Fig. 7: Cumulative distribution of rain-induced attenuation over elevation angle of 42.5^{o} at various Ku-and Ka-band frequencies.

Fig. 8: log normal fit for the comparison of the 1-minute rain rate with rain-induced attenuation

Conclusions

In this paper, the results of one-minute rain rate and rain-induced attenuation over Akure have been presented. The comparison of rainfall intensities shows that the average rain rate over the stations at 99.99 and 99.999 availability of time varies. Comparison of the CDF of rainfall intensity with the recent ITU–R P. 837-5 model shows that the model underestimated the rain rate value for 0.01% unavailability of time by about 38%. The investigation of the probability of rain occurrence for the various calendar months over the years reveals the importance of those months with a great probability of convective rainstorms. Further investigation into the dependence of average rain intensity on rain event duration show a correlation of 0.12 between the two quantities; while, diurnal variability revealed that both annual average rainfall intensity and heaviest rainfall intensity can occur at different hour of the day. The overall results indicated the importance of this type of statistical analysis from which a radio communications planning can be undertaken successfully in the region.

The results from the predicted rain attenuation over the Ku and Ka band frequencies show that at 0.01% of time, the rain attenuation exceeded varies between 15 and 34 dB for downlink/uplink frequencies of Ku band while at the Ka-band downlink/uplink frequencies, the rain attenuation varies between 34 and 116 dB. These results are vital for preliminary system design for telecommunication systems and for VSAT broadband-access initiatives in order to avoid the risk of over-estimating outages and thus over-designing microwave radio-communication systems in the region.

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