Adamawa State University Journal of Scientific Research
ISSN: 2251-0702 (Paper)
Volume 5 Number 1, April, 2017
http//www.adsujsr.com

Performance of Ku-Band Satellite Signals Received during Rainy Condition in two low Latitude Tropical locations of Nigeria

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Abstract

This paper presents results on the analysis of rain-induced attenuation on satellite communication links operating in the Ku band frequency over two low latitude tropical locations in Nigeria: Akure Southwest (7.3^{o}N; 5.3^{o}E, 358 m Altitude above sea level) and Jos Plateau, North Central (9^{o}57'N, 8^{o}58'E, 1192 m Altitude above sea level). The statistical analysis was based on the concurrently measured rainfall rates observed, signal strength and quality of a Ku-band satellite signal received during the occurrence of rainy events in the two locations. The study used sample data from two years of Ku band, EUTELSAT (W4/W7) satellite beacon footprint at a frequency of 12.245GHz and elevation angle of 036^{o}E over the region to determine the significance of rainfall intensity on the signal strength along the propagation paths. The Ku-band signal level and noise threshold for clear and non-clear air conditions were measured and recorded using the SATLINK digital meter. Concurrently, rainfall intensities were measured at one-minute integration time, using a Vantage-Vue Integrated Sensors Suite (ISS) weather station. Statistical analyses of the data were carried out using various EXCEL and MATLAB tools. Results indicated high intensity rainfall resulting in high levels of rain attenuation measured of about 16 dB in Akure and 10 dB in Jos. It was also found that rain rates as low as 10 mm/h were also accompanied by signal outages. This means that fade mitigation techniques (FMTs) employed for communication systems in the region do not provide the required QOS in terms of availability and reliability. Our findings further showed that the ITU-R rain attenuation prediction model over-estimates attenuation due to rain; and needs to be adjusted to the tune of about 15% in the two locations. Therefore, further research is required to develop suitable rain attenuation models and FMTs for tropical regions.

Keywords: Tropical region, Times series, Ku-band performance, Earth-Space propagation**.**

Introduction

A number of Ku-band satellite systems for both fixed and mobile communications services are now in used for different purposes among which are banking transactions, tele-medicine, tele-education, defense and the military to mention but few. In Nigeria for example, the Ku-band services is also on-board of NIGCOMSAT-1R, which need an extensive data base and accurate propagation model to decide the level of fade margin along the Earth-satellite link that could be implemented to achieve good Quality of Services (QOS). It has been reported that at Ku-band, the attenuation is less than 1 dB during clear sky, but can be up to 10 dB during raining condition (Mandeep, 2009, Nalinggam *et al.*, 2012) while signal attenuation levels are in excess of 20 dB in most tropical areas of the world (Kostulski, 2008).

Due to the congestion of communication services at frequencies below 10 GHz, there is an urgent need to utilize higher frequencies bands for both terrestrial and satellite communication links. However, it has been widely reported that, at higher frequencies bands, outages are related to the prevailing rain rates along the propagation paths (Ajewole *et al.*, 1999, Mandeep, 2009, Ojo and Falodun, 2012). It is prohibitively expensive to completely mitigate this degradation. To optimize system capacity utilization and cost, it makes economic sense to design satellite systems for an acceptable percent of time outage of 0.01% - which translates to system availability time of 99.99% (Dissanayake, 2002). In order to achieve the optimization, influence of hydrometeor (especially rain rate) on the propagation links must be investigated. There exist some unified and practical models based on the statistical description of the probability of exceedance such as the Crane-Global (1971), Crane-Two Component (1980), Dissanayake-Allnutt-Haidara (DAH) (2001) and the ITU-R models (1994 thru 2014); Garcia and Selvo (2004) to mention but few. The problem with some of these models is the applicability at the region different from where they were developed. This is the scenario at the equatorial and tropical region where few or no data are available. Often time attenuation due to rain is always obtained through prediction methods based on the 1-minute rain rate, which may not justify the true state of the dB actually needed by the system engineers for link designing, hence the need to carry out real time measurement of rain–induced attenuation for the region.

In this paper, the analysis of the real-time rate and rain-induced attenuation for link designing over two low latitude locations in Nigeria is presented. The analysis focuses on the time series of rainfall intensities and rain attenuation, cumulative distribution, seasonal and monthly variation and comparison of the rain-induced attenuation pattern over the observed years.

Materials and Methods

The experimental sites are at the Department of Physics, the Federal University of Technology Akure (FUTA), and Gold-and-Base (Near Airforce Millitary School), Jos, North Central Nigeria. Akure belongs to the rain forest region, South West part of Nigeria with an average rainfall amount of about 1480 mm per year. The State is often referred to as the sunshine state of Nigeria. Jos is one of the coldest parts of Nigeria (temperature may be as low as 6 ^{o}C during winter months) located in the midland region on a characteristics plateau with guinea savannah climate. The average rainfall amount is about 1200 mm per year. The two locations experience two major season: rainy season (March-October) and dry season (November-Middle March).

Beacon set-up and measurement of satellite signal

Rain-induced attenuation can either be measured with the use of a satellite beacon or radiometer; for this research a satellite beacon setup was used due to the availability of the equipment. Normally, the satellite beacon is a fixed-frequency un-modulated carrier transmitted by the satellite for reception on the ground, which is employed for the purpose of uplink control, telemetry and research. The rain attenuation measurement was set up at the Department of Physics, FUTA and replicated in Jos for the purpose of comparison between the two climatic regions. In the two locations, the satellite signal is received by the 90 cm offset parabolic dish, at an elevation angle of 53.2^o to the down converter and the beacon receiver. The down converted Ku-band signal from EUTELSAT W4/W7 was then fed to a digital satellite meter and a spectrum analyzer for signal level monitoring and logging into a computer unit.

The complete set up consists of the outdoor unit and the indoor unit connected together with a 75 Ω terminated coaxial cable. The outdoor unit comprises of the parabolic dish antenna mounted on a 3-metre pole and the low noise block amplifier, while the indoor unit comprises of the signal level monitor, a data logging TV-card system and a personal computer for user interface. The outdoor unit is located in the Radio Communication Research (RCR) garden of the Department of Physics, clear from Line of Sight (LOS) obstructions. The measurement set up is the same for Gold-and-Base in Jos except that the parabolic dish antenna is located on the top of the building, where there is no LOS obstruction.

The Low Noise Block Amplifier (LNB/A) and wave guide are mounted at the focal point of the parabolic dish. The LNB/A with noise figure 0.5 dB down-converts the EUTELSAT Ku-band beacon signal frequency of 12.245 GHz to an L-band signal of an intermediate frequency (IF) range of 950 - 2150 MHz for DTH use. The L-band signal through a digital satellite meter, is fed to a Thrillithic Tektronix spectrum analyzer which is operated with zero time span at the peak of the received spectrum of the satellite signal and the output of the video filter displays the received beacon signal level in milli-decibels (dBm) in digital video pictures, which are recorded on the PC via a TV-card and saved simultaneously into the data logger.

The logging system sampled data every second and integrated them at one-minute interval. The beacon levels are finally displayed in real time on the PC. The equipment downtime due to power issues adversely impacted on system availability. System availability for the data used for signal performance analysis and modeling is 90% for Akure and 83% for Jos. Rain-induced attenuation is obtained by estimating the difference between the measured received signal level and the reference level. The reference level is obtained by averaging the entire received signal level data on each month and at each place during no rain time (Maitra, 2004). Plate 1 presents the experimental set up while Table 1 gives the summary of SATLINK specifications used for setting up and calibrating the meter.

Precipitation set-up and measurement of rain rate

Both satellite signal performance and rain precipitation are measured concurrently. The precipitate measurement is made up of the Davis Vantage Vue weather station, which logs rain rate and other meteorological parameters (such as temperature, relative humidity, dew point, wind speed, heat index, pressure, solar radiation, ultraviolet index and evapo-transpiration (ET) index at one-minute integration time. The Davis station has an Integrated Sensor Suit (ISS), which is collocated with the outdoor unit of the beacon signal measurement setup i.e. the offset parabolic antenna. The resolution of the drop-count rain gauge is 1/60 mm/drop, a minimum detectable sensitivity and equivalent to the step size of the rainfall rate of 4 mm/h for 10 seconds. The resolution of the tip of the gauge is 0.5 mm/tip. The ISS is powered by a 0.5W solar panel backed up with a 3V Lithium cell (that may last longer than 2 years depending on solar charging. The rainfall rate was then used to compute theoretical rainfall attenuation suffered by the signal. Experimental observations during the period January 2013 to December 2014 have been used in the analysis for the present study.

Results and Discussion

Rainy events and rainfall characteristics in study locations

The rainy season within the study locations were further classified into: onset (Feb -Mar), peak (April-Sept) and the end (Oct - Dec). The classification is based on the number of rainy days in the specified months. It must be noted that November to January of the preceding year is included because scanty amount of rain sometime falls within these months.

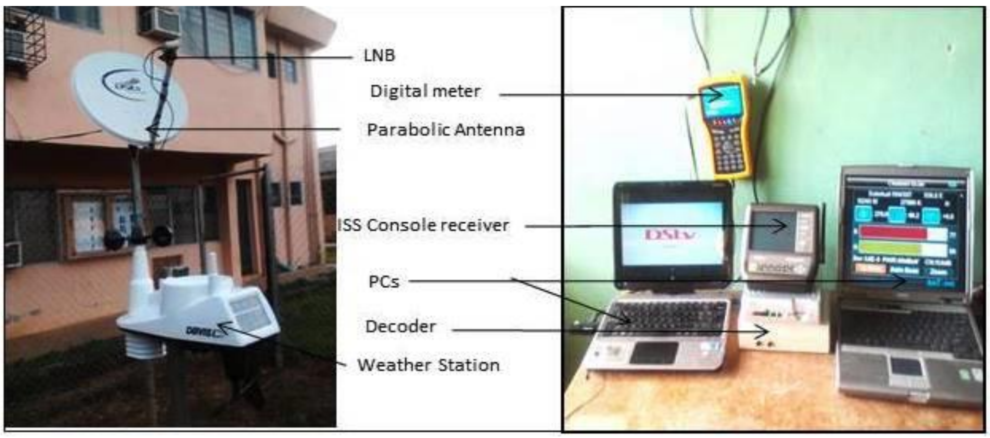

Plate 1: The experimental setup to measure rain rate and rain-induced attenuation.

Table 1: Specifications and parameters of satellite beacon links and sites

Parameters	Specifications	
	Akure	**Jos**
1. Downlink		
Polarisation	Horizontal	Horizontal
Transponder power (EIRP, dBm)	55.0	55.0
Frequency (GHz)	12.245	12.245
2. Receiving antenna		
Type	Offset parabolic dish	Offset parabolic dish
Size (m)	0.90	0.90
Gain (dB)	40.0	40.0
Beam width	0.29^0	0.29^0
3. LNBC		
Input signal (Beacon freq, GHz)	12.245	12.245
Local oscillator frequency, GHz	10	10
Amplifier gain, dB	50	50
Output signal frequency, MHz	950 -2150	950 -2150
4. External amplifier, dB	40	40
5. Spectrum analyser		
Type	SATLINK WS6936	SATLINK WS6936
Sampling interval	Infinite (1 second)	Infinite (1 second)
Centre frequency	12.245	12.245
Resolution Bandwidth	540M	540M
6. Earth station		
Longitude, Latitude	05 18'E, 07 17'N	08 57'E, 09 56'N
Azimuth angle	102.1	108.1
Elevation angle	53.3	56.5
Altitude (m)	358	1258
Distance from EUTELSAT satellite (km)	37,291	36,897
7. Weather parameters		
Max/Ave/Min Temperatures	45/28/15^{o}C	35/23/7^{o}C
Climate	Rain forest	Sudan Savannah
8. Satellite Parameters	EutelSat W4/W7	EutelSat W4/W7
Name/Number	(DSTV Multi-choice)	(DSTV Multi-choice)
Signal rate	036B	036B
Satellite elevation (Orbital)	27,509 bps	27,500 bps
Satellite Geo-station (Antenna Look-up)	036E	036E
Transponder power, EIRP (Max)	053.3E 85 dBmW	056.5E 85 dBmW
Commencement Date	June 2013	September 2013
Rain Equipment Integration time	Vantage Vue ISS weather station (One-minute)	

Annual CDF of rain rates comparison with ITU rain rate

The Cumulative Distributions Function (CDF) of rain rate in Akure and Jos are shown in Figure 1. The result is compared with the ITU-R predictions (ITU-R.P. 837-5, 2009) over the two locations. The most important input for system designers is the rainfall rate exceeded at the critical availability level of 0.01% of an average year, which translates to an outage of about 52 minutes in the year. The results from the figure shows that rain rates of about 120 mm/h and 100 mm/h are continuously exceeded for Akure and Jos respectively, at 0.01% of an average year. The implication is that for 52 minutes of every year, rainfall intensities were above 120 mm/h and 100 mm/h, for the respective locations - signifying the fact that the two locations and by extension the entire country experience intense rainfall which have huge adverse impact on propagation of radiowave especially at frequencies above 10 GHz.

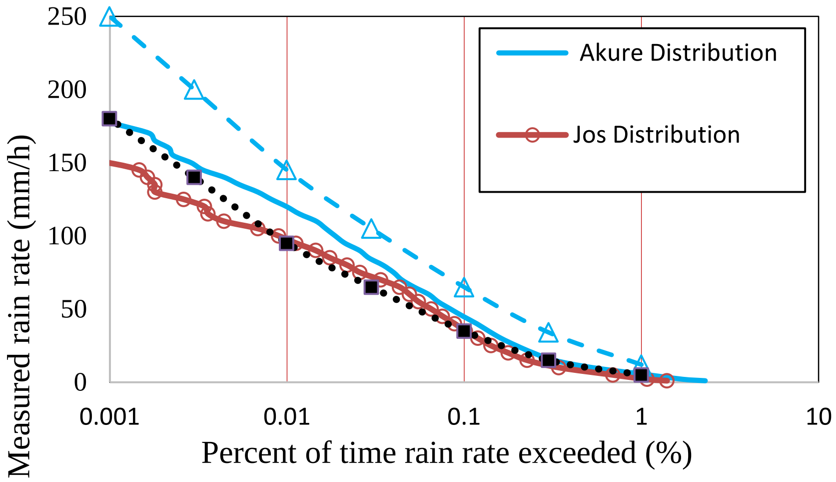

Figure 1: Cumulative Distribution of rainfall intensity over Akure and Jos

Comparison with ITU results show that ITU overestimates the rain rate results from Akure, while rain rates obtained from Jos conform with the results obtained by the ITU especially at time percentages between 1 and 0.008 % exceeded. The conformity of ITU rain rates with Jos results may be due to the climatic nature in this location which has similar pattern with the temperate region where most data applied in formulating the ITU rain model are obtained. However, at percentages exceedance < 0.008 ITU rain rates overestimated rain rates obtained at Jos location.

Times Series and Duration of High Intensity Rainfall

To identify the highest intensity rainfall rates, rainfall evolutions were classified into four types common to the tropical zone – thunderstorm, shower, widespread and drizzle – for rain rate ranges above 40 mm/h, 10 - 40 mm/h; 5 - 10 mm/h and below 5 mm/h respectively (Ajayi et al, 1996; Adimula, 1997). Some of the results are presented in this sub-section.

Figures 2 (a) and (b) depict results of rain event with high intensity on some typical days (The selection of days depend on the information of heavy rain rate (mm/hr) at the two locations). It was observed that irrespective of the two locations considered, rain rates above 60 mm/h could prevail for more than 18 minutes (1080 seconds), and such events could result in prolonged duration of signal fade outage in the regions.

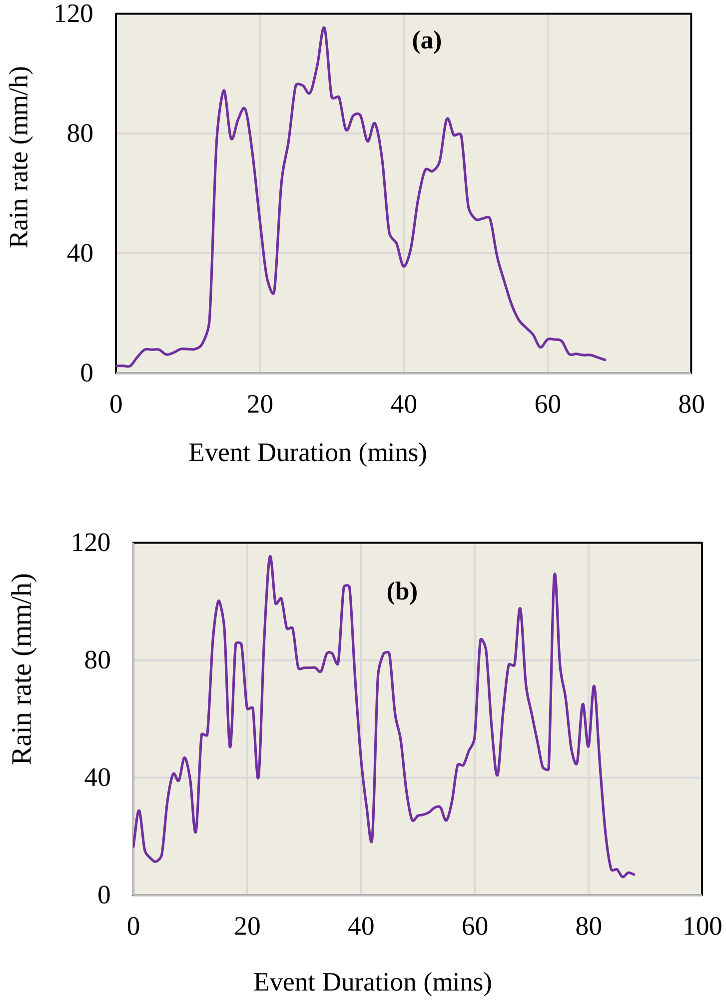

Figure 2: Typical duration of some high intensity rain events in (a) Akure Sept 26, 2014- LT: 11:29-12:37; (b) Jos April 17, 2014; LT 13:08-14.20

The duration of a given intense rainfall is useful to system planners and operators for estimating expected fades and outages due to rain attenuation (Ajayi, 1993). Hence, system designers need to take cognizance of this, since such occurrence can lead to total fade out of signal if proper compensation measure is not taken.

Characteristics of Rain Attenuation

For the analysis of rain-induced attenuation, beacon signals were recorded continuously for 14 months and 15 months in Akure and Jos respectively out of the observed years. During the period, the beacon receiver experienced some system down time as a result of power outage. Hence for the two years observation, 92 events that summed up to 6218 minutes of rain beacon signal data were recorded and retrieved at Akure station; while for Jos 86 events summed up to 5193 minutes of rain beacon signal data were retrieved and used for the analysis. In this section the measured attenuation data were used to quantify the degradations in two locations.

Figures 3 (a) and (b) presents the yearly results of rain attenuation for Akure and Jos respectively. It is seen from Akure graph that rain attenuation is more pronounced during the year 2013 as a result of the rain rate during the year when compared to the pattern in Jos. To be precise, while rain attenuation reaches up to about 52 dB with equivalent rain rate of about 480 mm/h in Akure, the maximum rain attenuation was about 14.2 db with equivalent rain rate of about 80 mm/h in Jos in the same year. Similarly, in the year 2014 Jos experiences less rain attenuation as compared with Akure. It could also be seen that over the 2 years of measurement, rain attenuation depth ranges between 6.5 and 25.5 dB, and 2.0 - 14.2 dB for rain rates in the range 30 mm/h - 150 mm/h in Akure and Jos respectively; while measure clear sky attenuation.

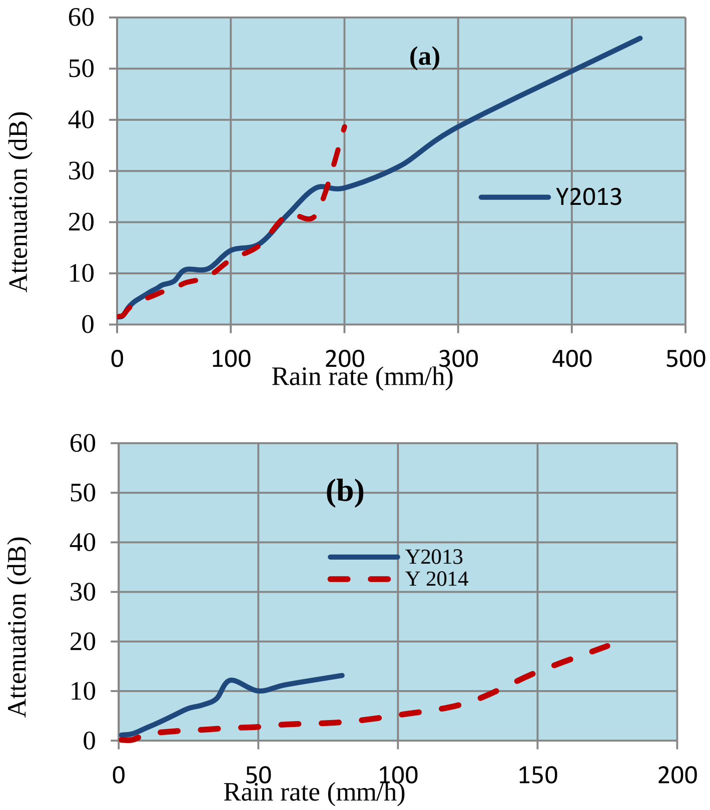

Figure 3: Yearly results of rain attenuation measured rain in **(a)** Akure and **(b)** Jos

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Values at the two locations are less than 1 dB . The implication of the results is that satellite signals are liable to more degradation during intense rainfall in Akure when compared to Jos and its environs. These results are in agreement with the observation that rain rates above 40 mm/h have strong impact on radiowave propagation (Ajayi, 1993) because of the preponderance of large raindrops that tend to breakup into a distribution of very small drop-sizes to cause severe interference to centimeter and millimeter-wave signals (Ajewole, 2003).

Time Series Attenuation during Some tropical rainy events

Time series of measured rainfall intensities and rain attenuation are used to display the signal performance during rain events. They are required for the determination of first and second order rain attenuation statistics which are used for the design and implementation of efficient fade mitigation techniques (Cheffena and Amaya, 2008). Samples of the time series analyses of rain-induced attenuation during some rainy events over Akure and Jos data are presented in Figures 4 to 7. The first observation is that the variation of the rainfall intensity during the rain event follows the negative exponential characteristics as earlier observed in the work of Capsoni *et al.*, (1987). For example, Fig. 4 presents the results of a typical rainy event (Thunderstorm rain type) observed on June 03, 2013 between the hours of 15:11 and 16:12 Local Time (LT) in Akure. It is seen that the variation of attenuation indicates **SQUELCHING** of signals for rain rates sometimes at low rain rate of about 10 mm/h.

The result presented during widespread rainy event as observed on March 30, 2014 between the elapsed time of 48 minutes (13:00 13:48 LT) in Akure (Fig. 5) also revealed some significant results that could be expected in such event. However, the effect is not as severe to satellite links when compared to the transmission during the thunderstorm rainy period. Similar results are also presented during thunderstorm rainy type (Fig. 6) and shower rainy type (Fig 7) in Jos. The time series generated from the simulation data are the essential input for developing and testing ACM schemes; and are used to compute further attenuation analysis as well as generate first and second order statistics such as fade slope, fade duration and inter-fade duration.

It could also be observed from Figures 4 to 7 that signal fade outs and **SQUELCHING** (or signal outage) occur a few minutes earlier than the occurrence of point rainfall. This phenomenon shows that rain cells responsible for attenuation occur at heights above the ground level and could serve as useful input for determining the spatial (both vertical and horizontal) characteristics of rainfall. The implication of the results is that the level (of signal thresholds) at which the received signal is squelched. At such points, there is complete signal fade out and attenuation is at the peak during rainy periods. Therefore, in Ku-band links, complete fade-outs set in at after a maximum of 5 dB. The flat anomalous response of signals to increasing rain rates is further captured in the monthly variability of rain attenuation and underlines the need for worst month analysis as required by ITU-R P.841-3.

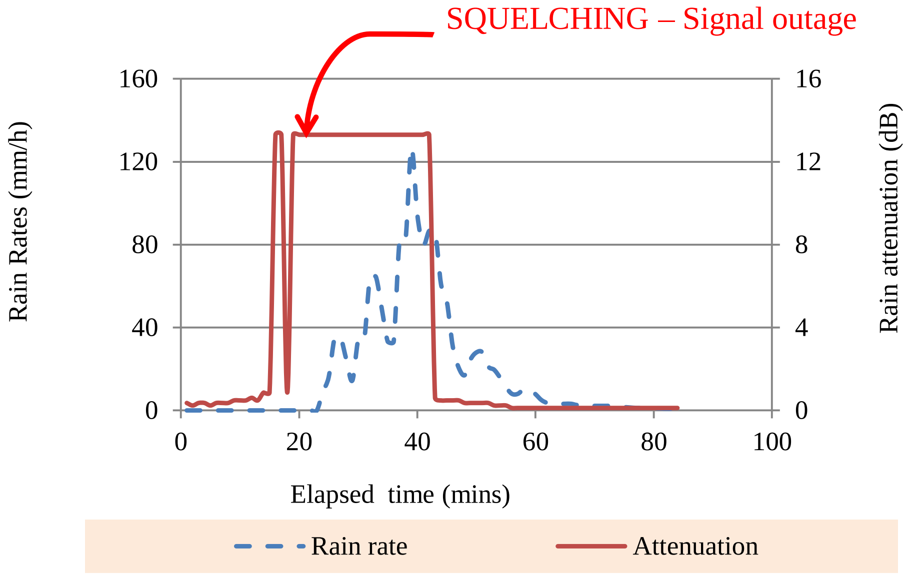

Figure 4: Typical degradation experienced during thunderstorm rain event on June 03, 2013 at the elapsed time of 15:11 - 16:12 LT in Akure

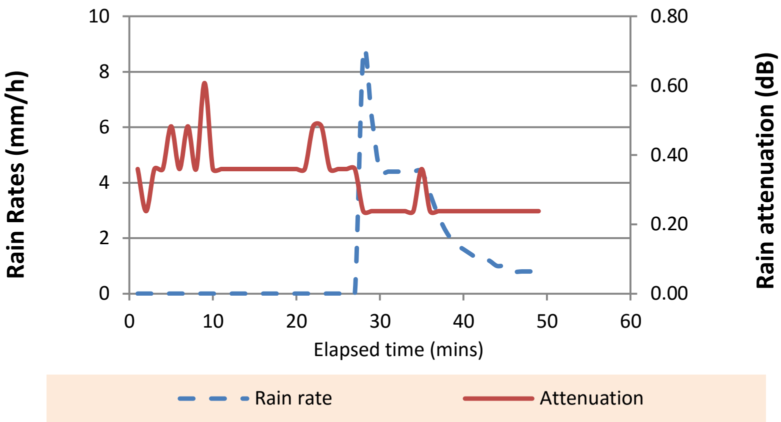

Figure 5: Typical degradation experienced during widespread rain event on March 30, 2014 at the elapsed time of 13:00 - 13:48 LT in Akure.

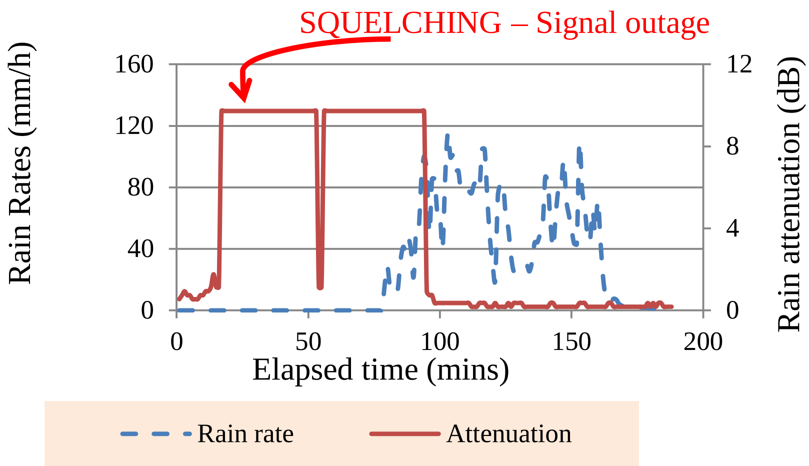

Figure 6: Typical degradation experienced during thunderstorm rain event on July 07, 2014 at the elapsed time of 16:00-17:32 LT in Jos

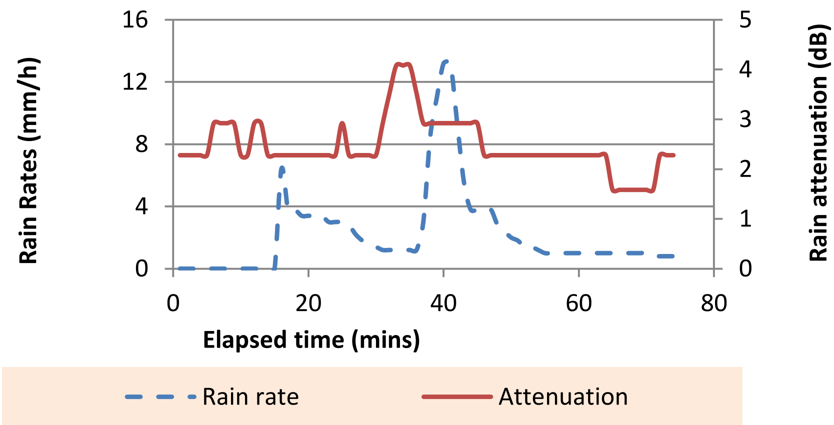

Figure 7: Typical degradation experienced during shower rain event on Sept 09, 2013 the elapsed time of 20:31-21:47 LT in Jos

A very good correlation between the attenuation of the satellite signal and the rain rate recorded by the rain-gauge is also observed. It could further been seen that during the Ku-band signal transmission, attenuation commences several minutes (about 10 to 15 minutes) before the onset of point rainfall, once there is cloud cover. The flat portion of the attenuation graph is the period of complete signal outage, when DTH output reads “NO SIGNALS”. At such points, the output from the digital meter reads: signal quality = 0; BER and CN – “NOT APPLICABLE” or indeterminable; Reference power level is about 16 dBμV. This **SQUELCHING** of signals occurs for rain rates sometimes as low as 10 mm/h.

Cumulative Distribution Function (CDF) and Variability of Rain Attenuation

The cumulative distribution of rain attenuation is the essential input for determination of fade margins. The values of rain-induced attenuation at the various time percentages represent the fade margin to be provided by the system designer. This section discusses results of the distribution of rain-induced attenuation measured over the Ku-band links at the two stations, as well as their annual seasonal and monthly variability. The analysis also includes the characterization of worst month concept. The main focus is to under study the implications for system planners at the various percentages of time.

Yearly CDF of Rain Attenuation over Akure and Jos

The cumulative distribution of rain attenuation derived from Ku-band beacon measurements over Akure and Jos during the period are shown in Figures 8. In general, the results show that measured attenuation in Jos is lower than those obtained at Akure; the margin is about 0.5 dB at lower availability levels (0.05 – 1.0%); and about 4 dB at higher availability levels (0.001 – 0.05%). The measured values were also compared with the predicted values by the ITU-R model for both locations. The results from both stations show very strong agreement with ITU-R most especially at the 0.01% of time. At lower availabilities between 99% and 99.9%, ITU-R over-estimate attenuation by an average error of about 15%.

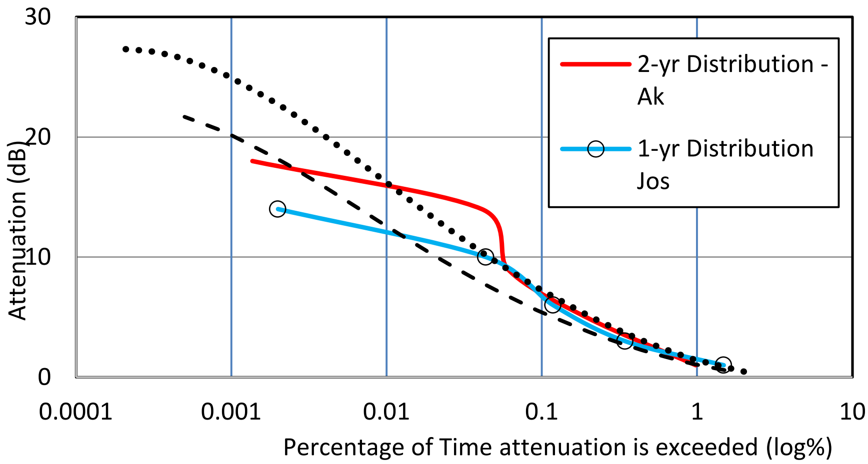

Figure 8: Comparison of CDFs of measured rain attenuation at 12.245 GHz over Akure and Jos in the study period (June 2013 – Dec 2014)

Monthly and Seasonal Variation of Rain Attenuation Distribution

The seasonal variation of rain attenuation over Akure and Jos are also presented in Figures 9(a) and 9(b) respectively. The results classified the rainy season into three namely- On-set, Peak and End of rain. Due to system break down, there were no attenuation measurements for onset of rains in Jos so comparisons were only made against the Average Year (AY). The results show that during the PEAK of rainy period, rain attenuation continued to exceed threshold values throughout all the time percentages from 2.0 to 0.005% of the time at Akure and Jos, while during the ONSET of the rainy period and END of the rainy period, rain persist for only a short part of the exceedance spectrum. It could also be seen that the worst months fall within the PEAK of the rainy season as earlier observed in the work of Nacokney and Davidson (1982).

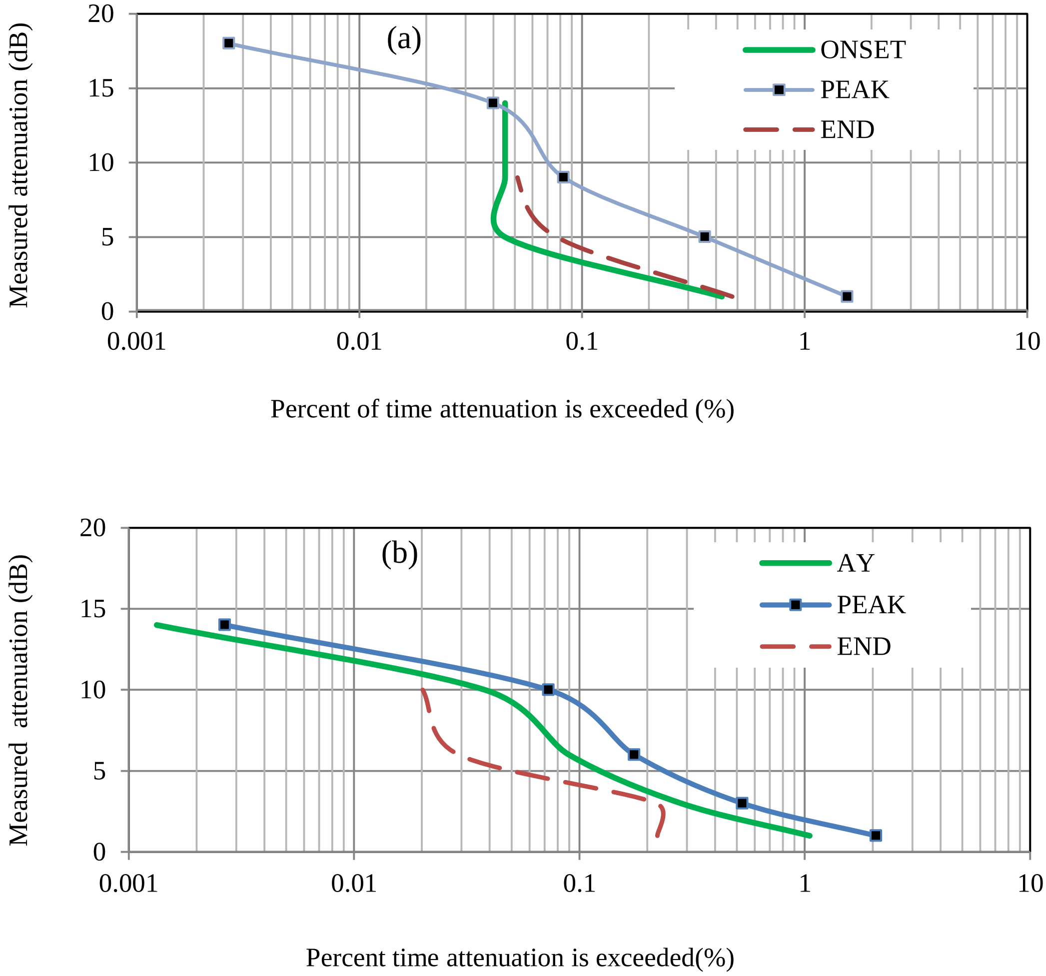

Figure 9: Seasonal variation of rain attenuation in the study period over (a) Akure and (b) Jos

The PEAK of rainy period was further subjected to monthly analysis and results presented in Figures 10 (a) and (b) for Akure and Figure 11 for Jos. It could be seen from the results for Akure that, the months with highest prevailing attenuation are June, July and

September for the year 2013, and the month of June in the year 2014. System designers must take significant of these months because they represent months within the year when signal degradation are prevalent. Similarly, the result for Jos shows that the month of June 2014 has the highest probability of exceedance and is selected as the worst month for 2014. However, more data are needed to validate the results.

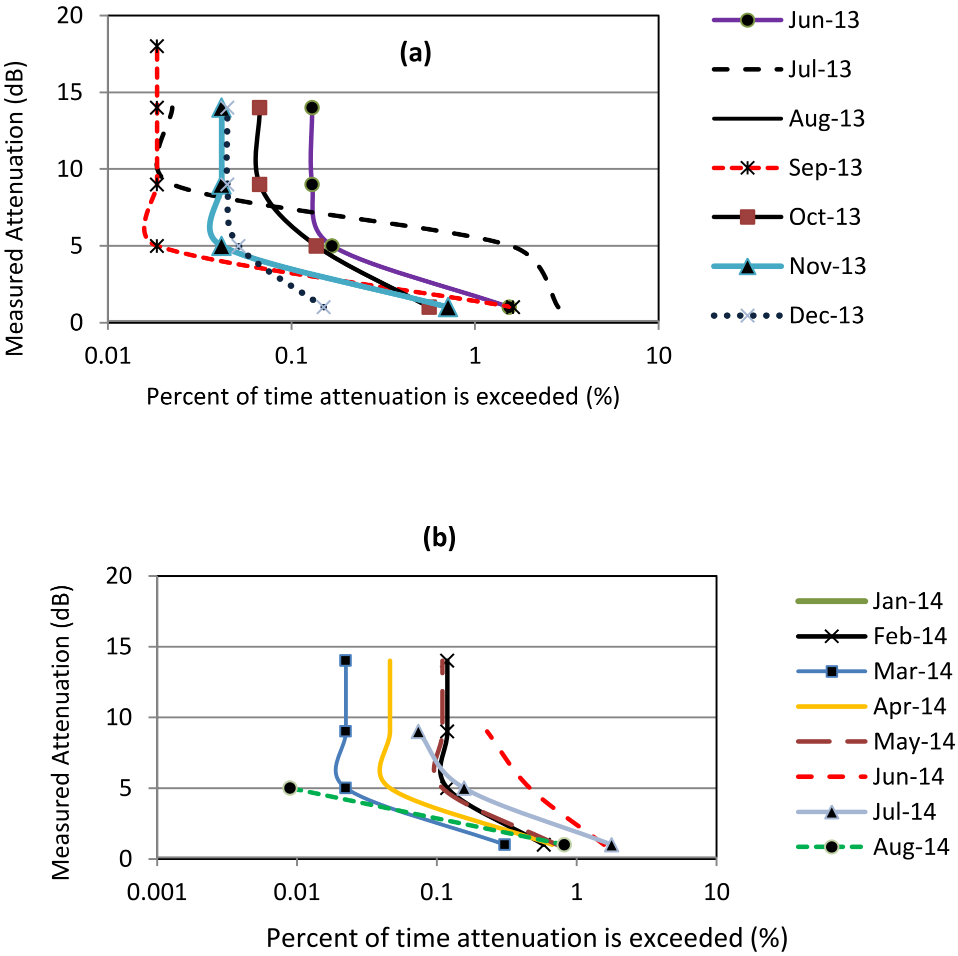

Figure 10: Monthly variation of measured attenuation at 12.245 GHz over (a) Akure, Jun-Dec, 2013 and (b) Jan-Aug, 2014

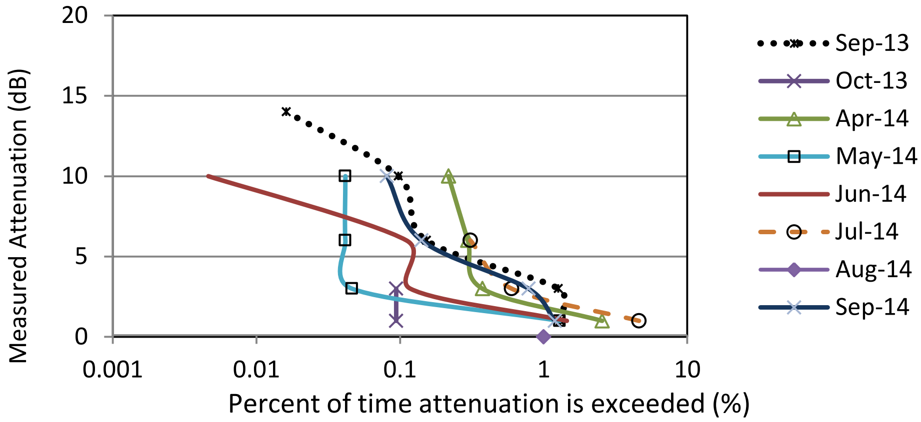

Figure 11: Monthly variation of measured attenuation at 12.245 GHz over Jos Sep 2013-Sep 2014.

Conclusion

In this paper, performance of Ku-band satellite signals during rainy conditions in Akure and Jos, Nigeria has been presented. Our result showed that the characteristic of rainfall in Nigeria at 99.99% availability is between 100mm/h in North Central and 120mm/h in the South West. Despite the difference in regional rainfall characteristics, both regions experience similar signal squelching and fade out. This high rain intensity is responsible for the severe degradation experienced in the propagation of satellite signals above 10 GHz in the region, as measured attenuation are 10 dB and 16 dB in the respective regions. There is an urgent need to embark on research efforts and develop fade mitigation techniques FMTs suitable for the region.

The problem is more compounded by our findings that, (FMTs) deployed on satellite communication systems do not provide the expected quality of service (QOS) in terms of reliability and availability, during rainfall. Ku-band signals (and generally, satellite signals) experience an attenuation which commences several minutes (about 10 to 15 minutes) before the onset of point rainfall, once there is cloud cover. Also, complete signal outage and **SQUELCHING** often occurred at rain rates as low as 10 mm/h.

This suggests that implementing a fixed fade margin may not offer the desired QOS and availability to users. More so, rain fade levels during worst months in both study locations are about 50% higher than levels in the average year; and increasing fade margin of the Ku-band link will be counter-productive because it will amount to increasing the link noise threshold. To deliver the required QOS, it is needful to design and implement alternate FMTs such as the Adaptive Coding and Modulation (ACM) and fade channel modelling. An ACM scheme would change from a pre-programmed power-efficient modulation scheme that mitigates system outage to another. Time series of rainfall during typical rainy events gave the reception pattern with very good correlation between the attenuation of the satellite signal and the rain rate recorded. Therefore they could serve as useful input for fade channel modelling techniques.

Finally, our findings revealed that, while ITU-R rain model grossly over-estimates rainfall characteristics in Akure, it is fairly suitable for predicting rainfall characteristics in Jos, probably because of its semi-temperate climate. There is need to explore and develop suitable rain attenuation models for the country as a whole.

Acknowledgment

The authors wish to thank the Department of Physics, Federal University of Technology, Akure, for the use of the Scintillation Lab and other facilities for the experimental set up.

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