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Comparison of the level of attenuation between a lower integration time and a higher integration time in a tropical location

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ABSTRACT

Rainfall is a vital factor that must be considered in the design of telecommunication systems. The challenges posed by rainfall at frequencies above 10 GHz on microwave terrestrial and space communication systems, especially in tropical and equatorial zones, is a major problem for the telecommunication engineer. In recent times, it has been observed that rain that fall within a very short period has more effect on radio signals than rain that occur at a longer period of time. Rain events can last for an extended period of time, but the most significant attenuation due to rain occurs during relatively short periods of very intense rainfall. In this work, 2 –year data collected using vertically-pointing Micro Rain Radar were used to determine and compare the level of attenuation and the result shows that the level of attenuation at lower integration times is more than the one that occur at higher integration times.

***Keywords*:** Rainfall, Telecommunication, Attenuation, Integration time, Micro Rain Radar

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1. INTRODUCTION

Over the years, rapid growth of wireless communications technology, especially in developing countries like Nigeria, causes the frequency bands to reach a saturated level. Due to this challenge, telecommunication systems engineers are exploring the frequency band above 10 GHz in order to meet the rapidly developing request for wide range bandwidth for transformation of the radio access network. The frequency band above 10 GHz is advantageous because it provides a wider spectrum and potential repeated use of frequencies and because the size of aerial and equipment is compact. These advantages can provide enough criteria for the development of telecommunication system. However, attenuation of radio waves due to atmospheric precipitation is a major obstacle to microwave and millimeter wave transmission at frequencies above 10 GHz. As the frequency increases, the wavelength of electromagnetic signal reduces to almost the size of rain droplet while the speed is constant (Robert et al. 2000).

Attenuation due to rain is more critical in tropical regions where there is high intensity rainfall. Most of terrestrial and satellite links designed for these regions must consider the attenuation given by each condition of rainfall, so that the communication systems are available all the time. Determining the specific attenuation for the specific rainfall rate is also very important. It is impossible to specify the accurate value of attenuation for a certain rainfall rate; however a prediction is a best method to find the nearest and persistent attenuation value. Several work have been carried out in order to determine and predict the attenuation by considering the rainfall rate, elevation angle, effective slant path length, storm and also polarization used. Rainfall rate statistics specified on a percent of time basis, (that is the percent of time in a year or a month that the rain rate equal or exceeds a specific value) is used in the rain rate attenuation (Mohammed et. al, 2009).

Among the various performance-affecting phenomena of interest, rain-induced attenuation is the most relevant (Matricciani and Riva, 1998), as the magnitudes of the fades exceed tens of dB at frequencies in the Ka (20 GHz to 30 GHz), Q/V (40 GHz to 50 GHz), or Extremely High Frequency (EHF) (20 GHz to 45 GHz) bands. These bands are in use for terrestrial services - such as wireless broadband access, local multipoint distribution service, and multipoint video distribution systems - as well as for satellite networks, part of the fixed and broadcast satellite services. 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 (Chun and Mandeep, 2013).

This scenario makes higher- frequency bands more attractive for the deployment of new systems. Examples of new communication systems foreseen to operate in the Ka and EHF bands are the IEEE 802.16 BWA standard - planned both in licensed and unlicensed portions of the spectrum, from 11 up to 66 GHz (IEEE, 2004), and the Digital Video Broadcasting family of standards for satellite communications - DVB-S2 (ETSI, 2006) and DVB-RCS (ETSI, 2005) Unfortunately, 1-min rain rate is seldomly available whereas rain rate in higher integration time is available in long term statistics (Ojo et al., 2016). This is because rain rate of higher integration time (daily, hourly, 30-min) are often used for weather forecast, agricultural purposes, climate modeling among others. The first, and most well-known, effect of rain is that it attenuates the radio signal passing through it. The attenuation is caused by the scattering and absorption of electromagnetic waves by drop of liquid water. The scattering diffuses the signal, while absorption involves the resonance of the waves with individual molecules of water.

Absorption increases the molecular energy, corresponding to a slight increase in temperature, resulting in an equivalent loss of signal energy (Robert and A. Nelson, 2000). Rain attenuation is one of most crucial factors to be considered in the link budget estimation for microwave satellite communication systems operating at frequency above 10 GHz. The statistical variation of rainfall and the fact that rain rate predictions model are still being refined to achieve better agreement with observed data, mean that rain attenuation prediction should only be considered as giving a general guide to system performance. Rain induced attenuation depends on frequency and rainfall intensity, or rain rate. Due to the statistical variation in rainfall rate, rain attenuation is given as a probabilistic value.

This is often expressed as rainfall rate exceeded for a certain percentage of time (usually 1% of the worst month). Attenuation is an important consideration in the modern world of wireless telecommunication. It also affects some vital aspect of human life services.

The services include tele-medicine, tele-education, defense, internet access, direct-to-home services (DTHs), electronic banking, oil exploration, fixed and mobile telephony among others. Rain attenuation increases with increase in rain intensity, thus leading to a decrease in the intensity of the signal reaching the receiver. Therefore, due to decrease of the received signal, interference from other system increases (Ojo *et al*., 2008).

Rain attenuation is by far the most important of losses for frequencies above 10 GHz (Mandeep and Allnut, 2007; Animesh and Kanster, 2005; Seybold, 2005; Crane, 2003; Charles, 2002;Walter et al., 2002 and Crane, 1982). ITU has recommended that rain attenuation of signals begin from 5 GHz and above (ITU – R 2001). Rain rate distribution is one of the most important factors for calculating rainfall attenuation (Mandeep and Allnut, 2007).

This attenuation depends largely on rainfall intensity R (mm/h) and rain drop size distribution (Oyedum, 2007; Walter, 2002). The most effective way of obtaining the cumulative rainfall distribution is through direct measurement. In some cases; rain rate of some locations may not be easily accessible. The specific objectives for this research work is to compare the level of attenuation that can be encountered under a short integration time and those of longer integration time.

2. OVERVIEW OF PREVIOUS WORKS

Harden *et al.* (1977) worked on the assessment of convective rain measured between 1970 and 1976, using rapid response gauges sited mainly in South-east England. The assessment was based on the statistical model for the temporal and spatial variations and the frequency of occurrence of intense rain events in the UK. Comparisons were further made with estimated long-term average values and models from other record. The relationship and models deduced was stated to apply in areas where rainfall conditions are significantly different from those occurring in the UK.

Ajayi and Ofoche (1983) made comparison on the effect of integration time on the cumulative distribution with the results obtained in other parts of the world. The conversion factors C_E and C_R obtained at Ile-Ife are observed to be lower than the values obtained at various locations in Europe. The number of occasions N(R) when a specified rainfall rate was continuously exceeded for durations of Δt seconds was found to obey the relationship:

$$N(R) = \alpha(\Delta t)^{\beta} \quad (1)$$

Ojo *et al.* (2008) presented tools for the prediction of rain rate and rain attenuation in the form of contour maps for Nigeria using a rainfall data bank of 30 years which are taken from measurements made from the coast to the arid region of Nigeria. Rain-rate maps for the country of Nigeria were developed using the models purposely designed for tropical zones while ITU-R models were used for the rain-attenuation maps. These maps show a good preliminary design tools for both terrestrial and Earth-satellite microwave links and also provide a broad idea of rain attenuation for microwave engineers. However, the data were converted from daily to 1-min integration time based on Moupfouma model.

Semire and Raji (2011) studied the characteristics of rainfall rate useful in the estimation of attenuation due to rain. Rain data collected at Ogbomoso between January–October, 2009 were used in the analysis. The result shows that power law relationship exists between the equiprobable rain rates of two different integration times. The value of conversion factors C_E and C_R obtained for Ogbomoso are 0.28(60) and 0.64(90) respectively. However, measurement period of 10 months may not be sufficiently enough to compare other literature result.

2. 1. Specific Attenuation

The fundamental quantity used in the calculation of rain attenuation statistics for terrestrial and earth – space paths is the specific attenuation (γ) or attenuation per unit distance (Olsen *et al*., 1978). Two general approaches have been used to calculate (γ) by various authors;

1) a theoretical method employing a uniform distribution of raindrops modeled as water spheres or more complex shape; and
2) an empirical procedure based on the approximate relation between (γ) and rain rate R given as (Olsen *et al*., 1978);

$$\gamma = kR^{\alpha} \qquad (2)$$

Equation (2) is known as the power - law form of specific rain attenuation (Zhang and Moayeri, 1999). R is the rain rate in mm/h, k and α are the power law parameters which depend on frequency, raindrop size distribution, rain temperature and polarization. This form is a method adopted in this research to compute specific attenuation. Values for k and α at 1 – 1000 GHz were calculated for rain rate with the assumed shape of oblate spheroids, at the temperature of 20 ºC, using the drop size distribution proposed by Laws and Parsons (1943). To find the total path attenuation due to rain, it is necessary to know the specific attenuation of the rain rate exceeded for the percentage of time of interest and the rain drop size distribution upon which the coefficient k and α depend (Ajayi *et al*., 1996). The specific attenuation, γ_R (dB/km) is obtained from the rain rate, R (mm/h) using the power-law relationship as stated in equation (5). However, the k and α used in this study were based on the ITU-R recommendations ITU-R, P.838-3 (2005) for vertical polarization because of the high intensity and short integration time associated with this type of rain. Table 1 presents the k and α parameter as presented by ITU-R Recommendation P.838 (2005)

2. 2. Rain

Attenuation Measurement Techniques

There are two techniques for determining rainfall attenuation, these are: indirect experimental measurements and direct prediction method. The indirect experimental measurements include: Radiometric techniques and Radar observation while direct prediction method make use of statistics of rain intensity data and frequency scaling methods. The direct prediction method was employed for this research since the research only focuses on Earth-satellite links as well as terrestrial radio links.

Table 1. The specific attenuation parameters given by ITU-R Recommendation P.838 (2005) for Vertical Polarization

Frequency (GHz)	K	A
1	0.000387	0.880
2	0.00154	0.923
4	0.000650	1.075
7	0.00301	1.312
*8	0.00454	1.310
10	0.0101	1.264
*12	0.0188	1.200
15	0.0367	1.128
20	0.0751	1.065
25	0.124	1.030
30	0.187	1.000
*35	0.263	0.963
*40	0.350	0.926

* refers to the frequencies used in this work.

2. 3. Effective Path Length

The effective path length L_e is usually defined as that parameter which relates the specific attenuation to the total attenuation along the Earth-space path. It is written mathematically as:

$$A = aR^{\alpha}L_e \quad (3)$$

where L_e is the hypothetical path length of uniform rain rate, R which relates the specific attenuation to the total attenuation along the path. The form of L_e and the technique employed for its derivation has been quite variable. For example, in some cases it is termed effective path length and in others the path averaging factor. Since rains are not usually uniform over the extent of the storm (rain cells of higher rain rates are small compared to the extent of the storm), the total attenuation is:

$$A = \int_0^L a_1 dl \quad (4)$$

where A is the total attenuation at a given frequency and time through the storm of extent L along the path l. The factor, a_1 is a "high resolution" specific attenuation depending on the rain rate at each point along the path. The effective path length in kilometers is denoted as:

$$L = A/a_{avg} \quad (5)$$

where a_{avg} is an analytically determined attenuation per kilometer assuming a uniform average rain rate. The average rain rate is based on rain rate measurements taken over a long period of time. The measured attenuation is also indirectly a function of the average rain rate. To measure the occurrence over a long time base. This removes the instantaneous time dependence of the measurements. Note that if rain rate is not a function of length l, then $A = a_{avg}L$ and the effective path length would equal the physical rain extent. This is one limit, which occurs for low rain rates.

For example, for stratiform rains the rain rate is nearly spatially uniform (Oort and Rasmussen, 1971).

2. 4. Rain Attenuation on an Earth Space Path

Earth – space paths traverse attenuating regions of liquid drops (rain) and regions of ice and snow in the atmosphere. The ice and snow contribute little to the attenuation and may be neglected (Crane, 2003 and Oyedum, 2007). So, rain is the major limit to system availability.

There are two aspects of rain attenuation studies over the earth space links.

i. The instantaneous relationship between the rain attenuation and point rainfall measurements.

ii. The statistical behavior of rain attenuation vis-à-vis rain rate at a particular location (Maitra and Chakravarty, 2002).

In both aspects, we lay emphasis on path attenuation. Path attenuation is essentially an integral of all individual increments of rain attenuation caused by the drops encountered along the path.

This is a physical approach to predict rain attenuation (Mandeep and Allnut, 2007). There are several factors that control the rain attenuation over the earth – space paths namely rain drop size distribution, rain height and rain cell size (Maitra and Chakaravarty, 2002). The degree of path attenuation depends on the frequency band. Specific attenuation increases with frequency and can be more than ten times higher at 15 GHz than 2 GHz (Crane, 2003).

Thus, we consider the signal band frequency, the satellite and its longitude, the path elevation and the receiving polarization tilt angle. Animesh and Kanster (2005) proposed that for a satellite 30– earth microwave link, the rapidity with which the attenuation changes, increases when the attenuation value gets higher.

This was experienced as they determined Ku and rain attenuation observation on an earth – space path in the India Region. In the pursuit of rain models, rain has generally been classified as stratiform, convective, or cyclonic. Location has everything to do with how much of this rain affect communication link.

3. RESEARCH METHODOLOGY

3. 1. Project Site

The measurement site for this study is the Federal University of Technology Akure, Ondo State (7° 17' N, 5° 18'E) which is in the Southwestern part of Nigeria. Akure has an average annual rainfall of 1485.57 mm and belongs to the P- zone of the ITU-R rain climatic zoning (ITU-R, 1994, Ojo and Ajewole, 2011). Although, the ITU-R recently proposed a location based model for predicting rain rate using the coordinate. Figure 1 presents the map of Ondo State showing where data were collected. The measurement was taken for a period of two years in Akure. The rain rate collected was at 10 seconds sampling time. The basic data employed for this study are rain rate data of 10-secs, 1–min, 5-min, 10-min and 15-min for a period of 2-years.

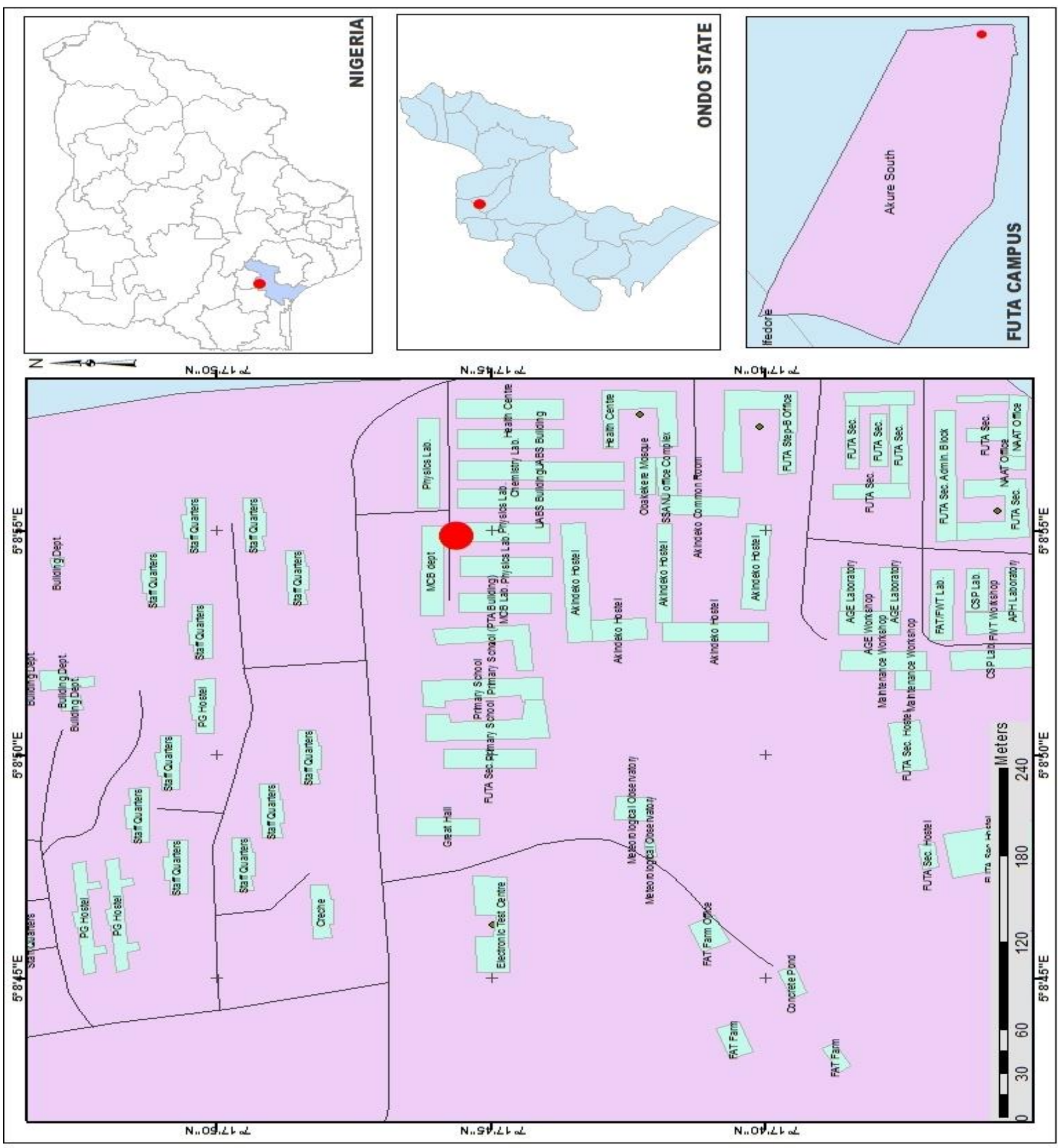

Figure 1. Map of Ondo State, Nigeria showing the site for this study.

3. 2. Instrumentation

Attenuation by rain can be predicted accurately if the rain is precisely described all the way along the path. Path attenuation is essentially an integral of all individual increments of rain attenuation caused by the drops encountered along the path. Hence micro rain radar data became indispensable for this study.

3. 3. The Micro Rain Radar (MRR)

The micro rain radar is a unique, compact 24.1 GHz frequency Modulated – continuous Wave (FM-CW) radar; for the measurement of vertical profiles of rain rate, liquid water content and Drop Size Distribution (Gerhard et al. 2002). It provides information for now-casting of precipitation i.e. it will detect the start of rain from the atmosphere to the antenna dish several minutes before the start of rain.

3. 3. 1. Outdoor Component

a) Offset parabolic dish antenna with 0.5m efficient aperture diameter and 24.1 GHz FM-CW transmit frequency cord
b) Radar front end (electromagnetic field)
c) Transmitter control electronic housing;
d) Recorder unit and digital signal processor unit for FFT (Fast Fourier Transform)-analysis for derivation of Doppler spectra (10s sampling time)
e) Data transmission with R5232 interface for system control f. 25m-junction cable for data transfer and power supply of outdoor components.

3. 3. 2. Indoor Component

a) Power supply 220VAC/24VDC/25W User can use either mains or 24VDC, as both are available

3. 3. 3. System parameter

a) Sampling time: 10s
b) Average time; adjustable; 10s to 1800s
c) Number of height steps: adjustable maximum is 30m
d) Lowest measuring height: 2 height steps
e) Automatic restart after power breakdown with fewer settings.
f) Output of measured data [spectra reflectivity, rain rate, Liquid water content and Drop Size Distribution (DSD)] both as instantaneous and averaged data (with selected averaging interval) NOTE; for the data transmission of the Doppler spectra from the outdoor receiver and FFT electronic to the indoor data acquisition PC; a transfer time of 2-3s are used for effective measurements.

3. 3. 4. General features/functions of MRR

a) Vertical profiles of rain rate and liquid water content up to 6km.
b) Computes detailed Drop Size Distribution output.
c) User adjustable averaging intervals and height resolution.
d) High system reliability e. Very little maintenance

e) Remote/long term unattended operation.
f) High quality measurements h. No wind, sea spray or evaporation induced errors.
g) Adjustable averaging intervals 10-1800s

Figure 2(a). Diagram showing the outdoor unit of a MRR, Located at Physics Department, Federal University of Technology Akure.

Figure 2(b). Diagram showing the indoor unit of a MRR, Located at Physics Department, Federal University of Technology Akure.

3. 3. 5. Methodology

The specifications of the vertically pointing MRR FM-CW mode for data collection is presented in Table 2. Other items to enhance performance of the MRR are optional and mainly suited for ice and snow regions of the world.

3. 3. 6. Retrieval of Microphysical Distributions and Parameters

This is the analysis of how the MRR displays various ranges of required data on the screen. To achieve this; the MRR makes use of a GRAPHIC-SOFTWARE. There are two pieces of this software supplied with the MRR. The first is the controlling software to set the parameters; and the second is software to view the Doppler spectra and visualize the data graphically for presentation. Functionality can be broken down as

a) Software module for system access and control, data transfer and data storage.
b) Software module for on-line evaluation of Doppler spectra (measured data)
c) Software module for graphic presentation of results and data with profiles, time series and droplet spectra, in a single graphic format, selectable time and height ranges, smoothing functions and printer output.

Though this latter software data is not used in this research, the PC computer for this software must have the following configurations for either the desktop models or notebook model. For desktop models: 600 MHz, Pentium M, 64MB, Windows 2000 or XP, VGA monitor, 20.0 GBHD, CD writer, 1.44 Floppy, 1 serial, 1 parallel port; NOTE.

Table 2. Specifications of the vertically pointing MRR

Specification	Capacity
Transmit power (mW)	50
Frequency (GHz)	24.1 to 24.15
Averaging interval (s)	10 to 3600
Height resolution (m)	10 to 200
Number of range gates (m)	up to 30
Accuracy for 1min average (mm/hr)	1/100
Power supply	(mains driven or 24 VDC)- 24 VDC,25W
Weight (kg)	6 (without power supply cable)

The serial port must be native and not provided over a PC card USB to serial adapter, as these tend to be unreliable or cause conflicts. For Note book models; Windows 2000 or XP, 600 MHz, Pentium M, 64 MB, 14.1 TFT VGA monitor, 8.0 GBHD, external CD-writer, 1.44 floppy, 1 serial , I parallel port; 2 PC- cards slots. NOTE: The serial port must be native also and not provided over a PC card or USB to serial adapter, as these tend to be unreliable or cause conflicts. With this; the Radar can display several values about the rainfall, Drop Size Distribution, Volume reflectivity, Liquid water Content and Rain rate.

4. RESULTS AND DISCUSSION

To obtain the path attenuation due to rain, it is necessary to know the specific attenuation of the rain rate exceeded for the percentage of time of interest and the rain drop size distribution upon which the coefficient *k* and α depend (Ajayi *et al*., 1996). The specific attenuation, γ_R (dB/km) is obtained from the rain rate, R (mm/h) using the power-law relationship as stated in equation (2). However, the k and α used in this study were based on the ITU-R recommendations ITU-R, P.838-3 (2005) for vertical polarization because of the high intensity and short integration time associated with this type of rain. Figure 3 (a) – 3(c) shows the variation between specific attenuation and rain rate within the two years.

Figures 4 (a) - 4(c) also present the attenuation predictions due to rain at different frequencies of 8, 12, 35 and 40 GHz for 10 sec rain rate, 1 min rain rate and 5 min rain rate respectively. The results showed that attenuation decreases as the integration time increases and the frequency of operation increases. For example, in Figure 4(a) for 10 secs integration time at 8 GHz, the values of attenuation range between 0.770 dB and 12.94 dB.

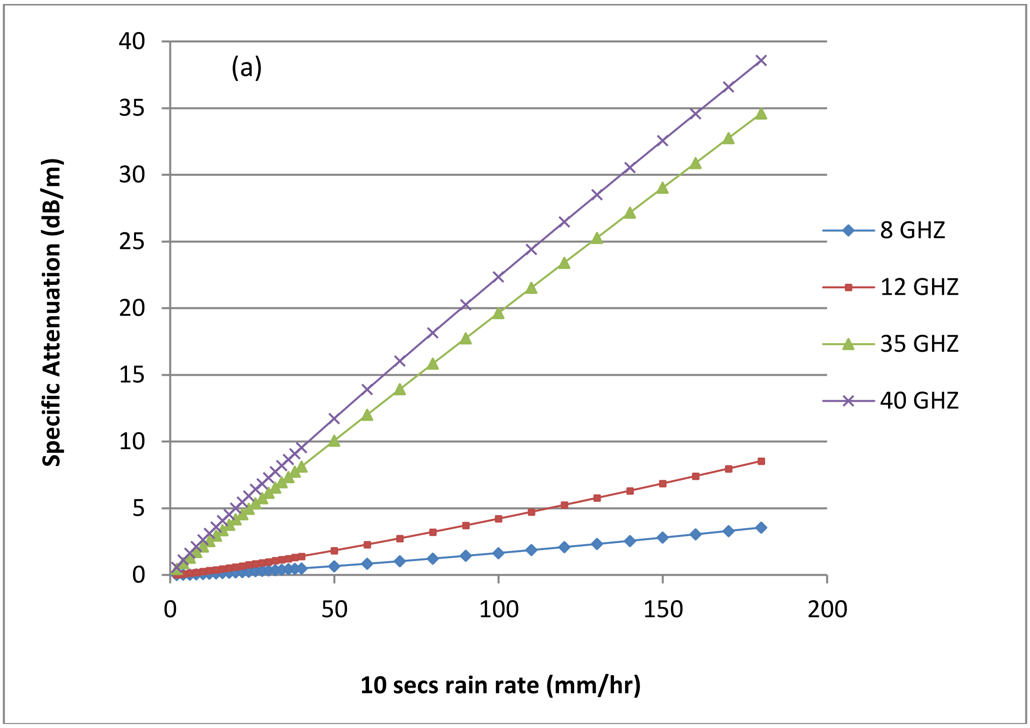

Figure 3(a). Variation of specific attenuation with rain rate at different frequencies for 10 secs integration time

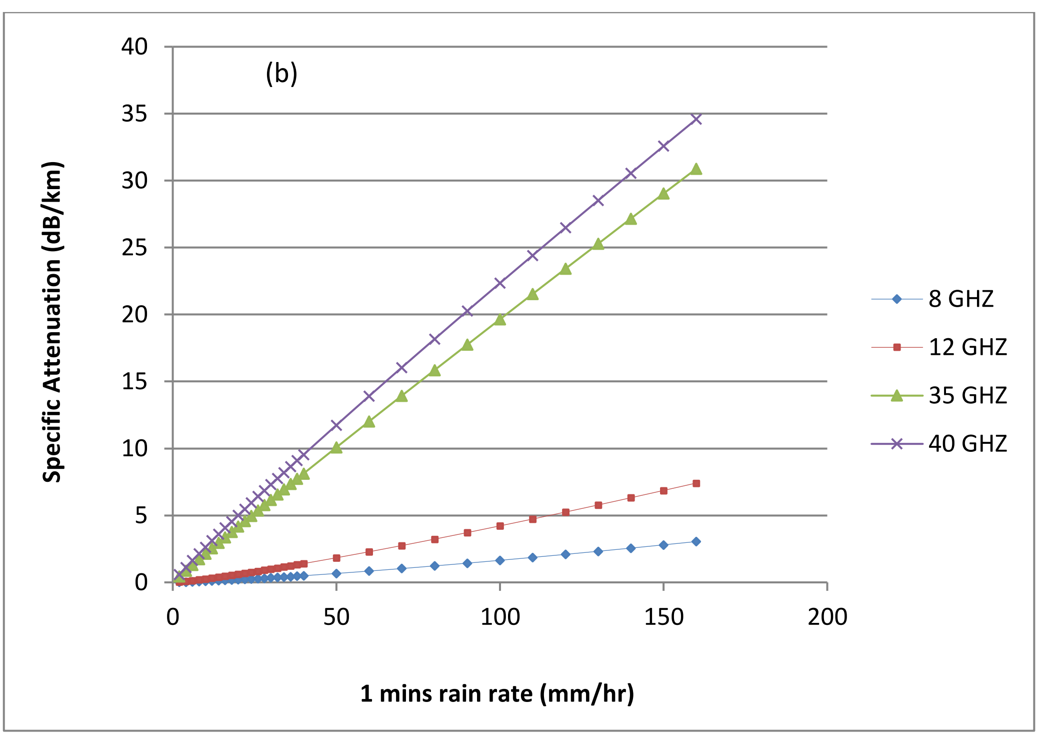

Figure 3(b). Variation of specific attenuation with rain rate at different frequencies for 1-min integration time

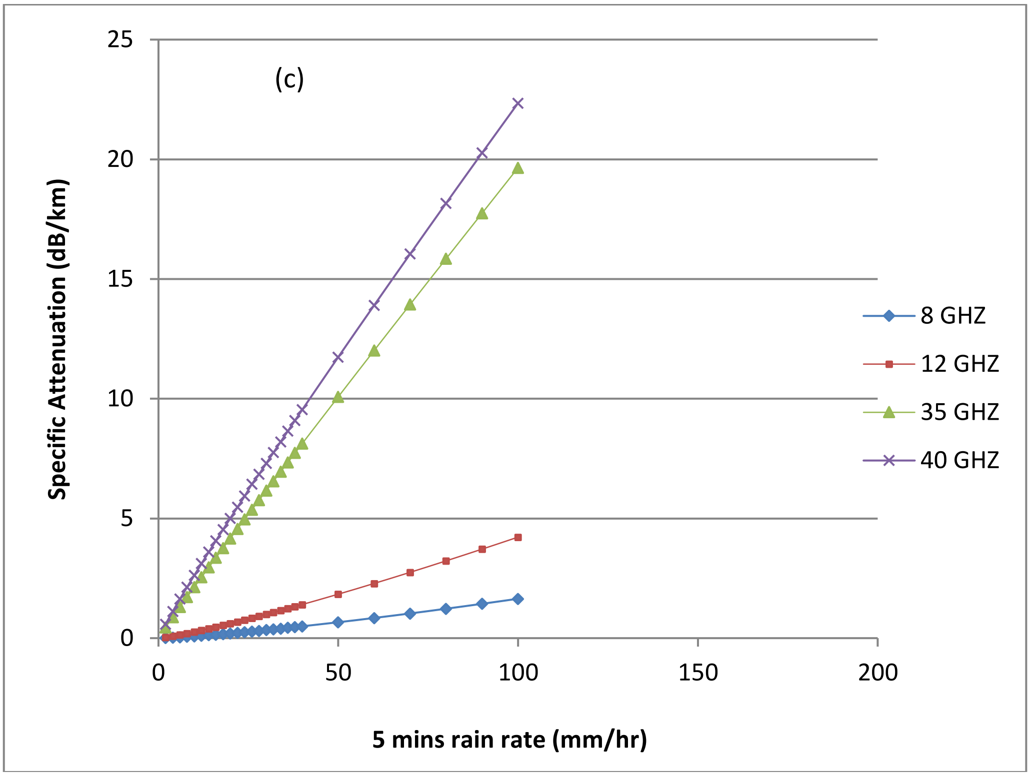

Figure 3(c). Variation of specific attenuation with rain rate at different frequencies for 5-min integration time

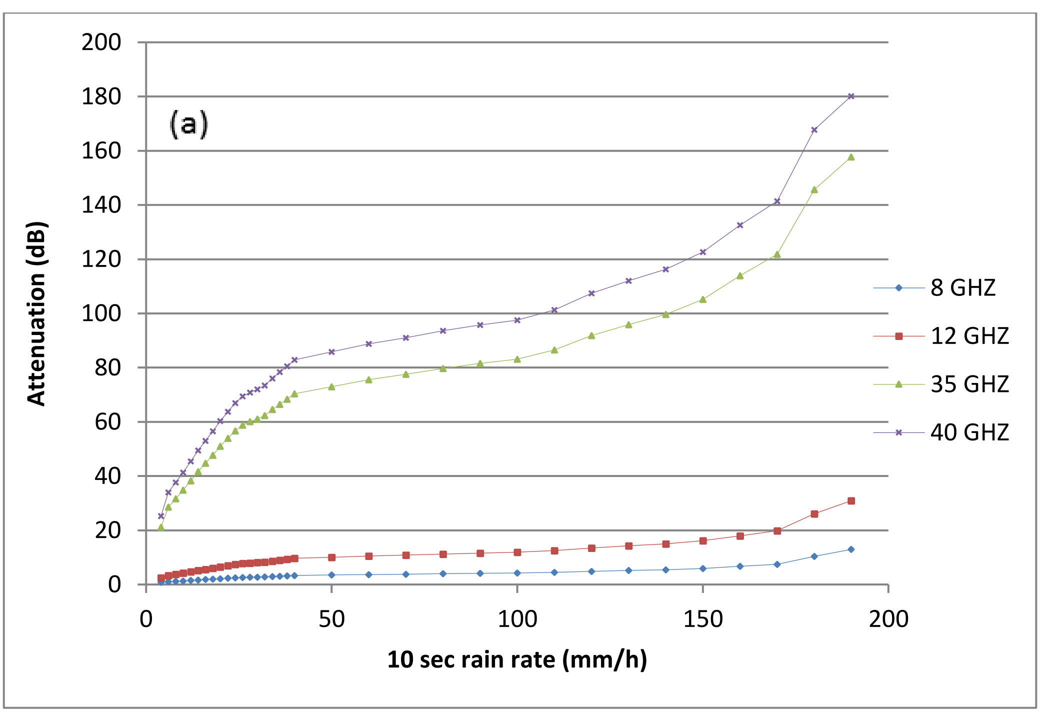

Figure 4(a). Rain Attenuation at 0.01% exceedance for different frequencies at 10-sec integration time.

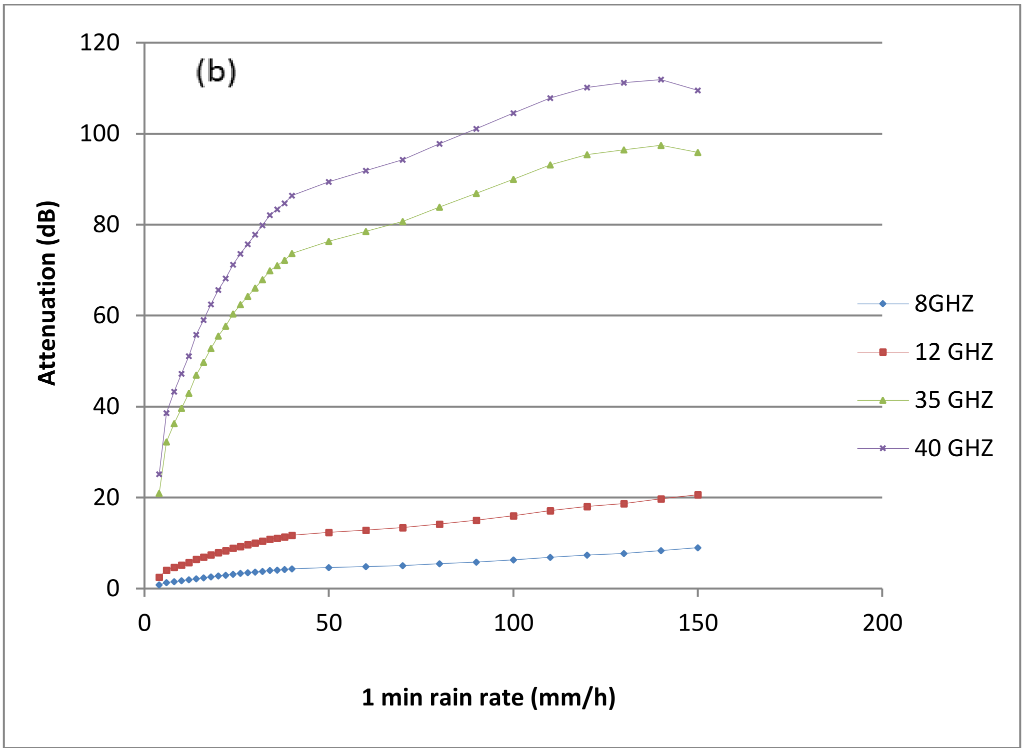

Figure 4(b). Rain Attenuation at 0.01% exceedance for different frequencies at 1-min integration time.

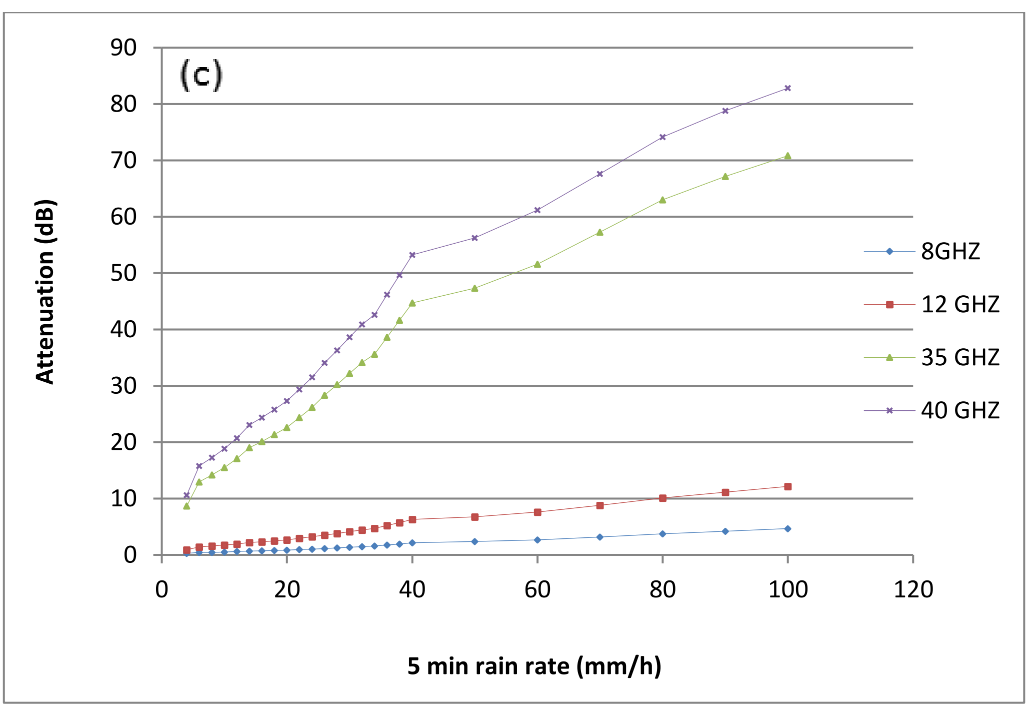

Figure 4(c). Rain Attenuation at 0.01% exceedance for different frequencies at 5-min integration time.

Also at 12 GHz frequency, it was observed that the minimum attenuation value is 2.441 dB while the highest attenuation value is 30.92 dB. Considering frequency at 35 GHz the attenuation values also ranged between 21.14 and 157.7 dB. For 40 GHz the attenuation values also ranged between 25.22 dB and 180.2 dB. The same trend continues at other integration time although with different values of attenuation. The overall result revealed that signal reception from the satellite will be severely attenuated as the frequency increases. Out of the three integration time considered, signals are most attenuated at 10 -sec integration time and least attenuated at 5 -min integration time. This show the significant of integration time considering prediction of rain attenuation for satellite system applications.

5. CONCLUSION

A 2 years data collected from Micro Rain Radar at Akure, Nigeria have been utilized to study the comparability of the level of attenuation that can be encountered under a small integration time and those higher integration time. The results showed that attenuation at lower integration time is more severe than that at higher integration time. It is observed that of the three integration time considered, signals are most attenuated at 10 -sec integration time and least attenuated at 5 -min integration time.

Recommendations

As communication networks are growing faster in Nigeria, it is suggested that more research should be carried out using appropriate parameters which of instantaneous rainfall rate of 10- secs integration time and up-to-date instrumentation (such as Rapid Response Rain gauge, Disdrometer, among others) to determine the level of attenuation at a lower integration time. This will help the scientist and engineers on link budgeting design.

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