CATEGORIZATION OF MEASURED RAINFALL RATES AND ESTIMATION OF THEIR IMPACT ON RADIO WAVE PROPAGATION AT HIGHER FREQUENCY BAND (12.5 GHz) IN WUKARI, TARABA STATE, NIGERIA.

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ABSTRACT

This study presents the categorization of measured rainfall rate and estimation of their impact on radio wave propagating at 12.5GHz. Rain rate at one minute interval were measured using Davis Vantage Vue weather station which is equipped with an integrated sensor suite (ISS) and weather link data logger. The rainfall rates were measured and categorized into Drizzle (≤5mm/hr), Widespread (>5≤25mm/hr), Shower (>25≤50mm/hr) and Thunder (>50mm/hr). The results obtained revealed that the impact of drizzle (≤5mm/hr) on the radio signal is not significant regardless the duration of rainfall. The results also revealed that severe signal losses recorded under shower (>25≤50mm/hr) and thunderstorm (>50mm/hr) were due to a greater value of BER ($\geq 10^{-9}$) which affected and reduced the level of the received signal as such limiting the performance of the propagated signal under rain. This is because, for a satisfactory performance of radio link under rain, the measured BER should be less than 10^{-9}as recommended by ITU-R. The results further revealed that widespread (>5≤25mm/hr) that prevailed for a longer period also causes severe signal losses. This is to say that lower rain rate of about 25mm/hr that prevailed for a very long time have significant effect on the propagated signal.

Keywords: Rainfall rate, radio wave, frequency band, and Radio Propagation

INTRODUCTION

Before now radio waves were propagated in lower frequency either within 3GHz (Zhimwang et al, 2018). Presently, more advanced telecommunication applications are in use and have led to the congestion of the lower frequency bands and utilization of higher frequency above 10GHz which offers larger bandwidth, frequency reuse, and better spectrum availability has become a necessity so as to support advanced services like video streaming, data communications, voice services among others (Yahaya et al, 2022; Zhimwang et al, 2018; Odesanya et al, 2022; Abdullah et al, 2012). The environment where radio waves are been propagated often introduce multipath effects causing fading and channel time dispersion among other impairments. Various propagation environments have different path loss and multipath effects, leading to the impossibility of radio wave propagation prediction in different propagation environment with the utilization of the same propagation channel model (Abayomi and Khamis, 2012; Dissanayake, 2002). Radio wave propagation at higher frequency especially at 12.5 GHz is usually characterized with signal fading or losses due to adverse weather condition as a result of atmospheric gases, fog, cloud, rain among others (Fadilah and Pratama, 2018; Fikih et al, 2011). The effect is always more pronounced in the tropical region associated with high relative humidity, cloud formation and high rainfall rate (Igbekele et al, 2020; Odesanya et al, 2022; Syed et al 2017).

Rain is the major parameter to consider when designing radio communication link budgets. Attenuation due to rain is a dependent of frequency and the rainfall rate (Ezeh et al, 2014; Igbekele et al, 2019). Rain causes signal degradation for radio communication systems operating at higher frequency, especially in region like North-Central Nigeria that experience heavy amount of rainfall annually (Ayantunji, et al,2013; Khoshkholgh et al, 2016; Modupe et al, 2020). Rain attenuation causes a greater power requirement from the transmitting units which hence lead to a higher cost per bit of transmission. Previously, Researchers have make several efforts to estimate the impact of rainfall rate on radio wave propagation though ignoring the fact that rain activities often varies making it inconsistent with time. This is why sometimes under the rain activities, the received signal strength may be good or very poor. Therefore it is very imperative to categorize the rainfall rate to be able to ascertain at what point or category of rainfall rate is the transmitted radio signal affected. This will enable telecommunication operators to make accurate prediction of the models to use for their link and also reduce cost of operation. This is why this study aimed at categorizing the measured rain rate in North-central Nigeria and estimating their impact on telecommunication link operating at 12.5GHz frequency band.

Previously, (Modupe et al, 2020) worked on 1-minute rain rate distribution for communication link design based on ground and satellite measurements in West Africa. There work focuses on analyzing the rain rate from six countries in West Africa, namely Benin, Cameroon, Cote d'Ivoire, Ghana, Nigeria, and Togo. Three locations were selected in each country. Rain data were obtained from the Tropical Rain Measuring Mission-Precipitation Radar (TRMM-PR) and the Global Precipitation Measurement (GPM) missions, and Tropospheric Data Acquisition Network (TRODAN) weather stations in Nigeria. They used ITU-R and Moupfouma models for the conversion of the 5-minute rain rate to 1-minute integration time at a probability of exceedance ranging from 1% to 0.001%. The cumulative rain rate distribution from the measured rain rate is presented alongside the predictions of the models. ITU-R and Moupfouma predicted similar results at 0.1% probability of exceedance. ITU-R overestimates the rain rate above 0.01% probability of exceedance.

Study on statistical characteristics of tropical rain rate and rain intensity from radar and rain gauge measurements examined the statistical distributions of rain rate have for tropics and compared with the temperate zone using standard model and meteorological data contained in the International Radio Consultive Committee (CCIR) report. A number of mathematical functions valid within a certain range of probabilities have been implemented to model rainfall intensity statistics. Emphasis was given on the return periods of precipitation rate in the context of microwave communication. Rapid response rain gauge measurements at three locations in India are analyzed and some interesting results were presented (Bhattacharya et al, 2007). According to (Fadilah and Pratama, 2018) rain attenuation is one of the factors taken into consideration in the telecommunication system using frequencies above 10 GHz. The objective of the research was to know the rain attenuation value estimation that used in link budget communication design to compensate the appropriate margin in LAPAN communication satellite. The study compared the rain attenuation estimation using ITU-R, Global Crane, and DAH modeling. The highest estimated rainfall value is found in Pare-pare using the Global Crane method. Also, (Anaka et al, 2021) worked on Modeling of the Rain

Rate and Rain Attenuation for the Design of Line-of-Sight Link Budget over Warri, Nigeria. Their work concluded that ITU-R model remains the most standard model for designing LOS link due to the moderate rain attenuation either signal losses obtained compared to the Moupfouma model. The impact of rain attenuation on received signal was investigated and also the cumulative distribution function calculated was used to predict at what point a signal is meant to be stable and the effect of attenuation on LOS link budget was computed using ITU-R and moupfouma model.

For this study, we did not only find the impact of rainfall rate on propagated radio wave as done by previous researchers but we also focused on categorizing the measured rainfall rates and estimating the effects of each categorized rainfall rate on radio wave propagation within the study location.

CATEGORIZATION OF RAINFALL RATE

Rainfall is broadly categories into drizzle, widespread, shower and thunderstorm. The drizzle is a category of rain which consists entirely of small rain drops usually of diameter less than 1 mm and commonly falls in damp weather from shallow layer clouds. It is characterized by very low rainfall rates with typical values not greater than 5 mm/h either ≤5mm/hr (Ajewole, 2011; Anaka et al, 2021). Widespread rainy events usually have intensity between about greater than 5mm to 25 mm/h and the intensity may be practically constant or change only gradually during precipitation. The duration of widespread rain event may be several hours. The shower type of rain on the other hand originates from cumuliform clouds. This type of rain is characterized majorly by high intensity values, ranging from about 25 mm/h to about 50 mm/h and raindrops with diameter greater than 2 mm. It is formed below the Zero Degree Isotherm (ZDI) height through the process of accretion. Its formation is due largely to the rate of accretion, the thickness of clouds, and the strength of the up draughts. The thunderstorm rain is usually generated within the cumulonimbus cloud systems. During thunderstorm activity, the precipitation particles grow in size until they grow large to become drops of diameter greater than about 3 mm and are no longer supported by the upward currents. At this stage, they fall to the ground with values of rain rate between about 50 mm/h and 240 mm/h (Ajewole, 2011; Khoshkholgh et al, 2016; Yahaya et al, 2022).

EXPERIMENTAL SITE AND SETUP

The experiment was carried out in Wukari Taraba state (7.93° N, 9.81° E). The equipment used for this research includes the following: Rain gauge (Davis weather station), Spectrum Analyzer (WS-6936), USB data logger, computer system, parabolic reflector antenna, Compass, Radio frequency power meter, Coaxial cable port connector and connecting cable (coaxial cable). Figure 1 shows the experimental setup. The availability of the weather station and satellite system beacon signal measurement was 90% being powered by a solar panel and a battery as standby. The experimental set up was used to concurrently measure and record rain-rate, Bit-Error-Rate and radio signal strength for the months of April, May, June, July, August, September and October 2021. The rainfall rates were used to formulate models that relate to the distribution of rainfall intensities to the impairments caused by different categories of rainfall.

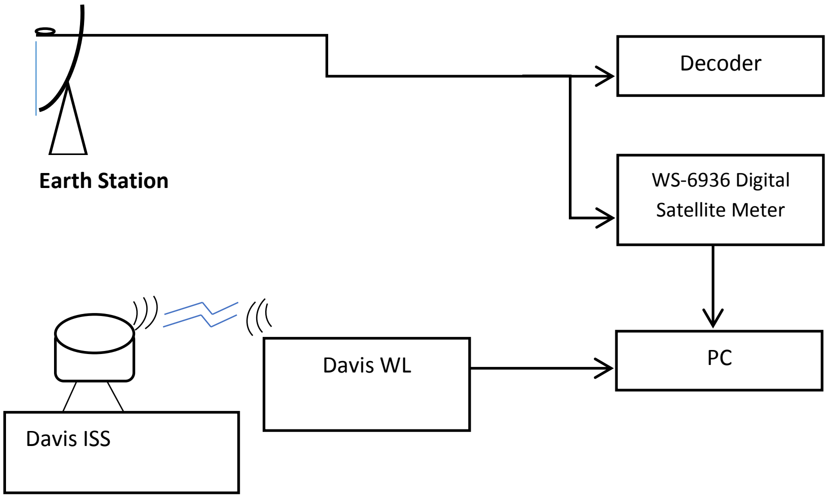

Figure 1: Experimental Site Setup

As shown in figure 1, the rain rate data was measured using Davis Vantage Vue weather station which is equipped with an integrated sensor suite (ISS) and weather link data logger, and was used to measure and record one-minute rain-rates. Its electronic weather link console serves as the user interface, data display and analogue to digital converter, and has capacity to log 2560 measurements. The rain gauge instrument is a self-emptying tipping spoon, with gauge resolution of 0.2 mm per tip. It is able to measure rainfall rate from a minimum of 0.8 mm/h up to a value of 420 mm/h, with an accuracy of 0.2 mm/h.

ESTIMATING THE IMPACT OF RAINFALL RATE ON RADIO SIGNAL

The impact of each categorized rainfall rate either drizzle, shower, widespread and thunderstorm were estimated by the losses they cause on the transmitted radio signal that results to poor received signal strength and high level of bit-error-rate (BER). For this study, the BER and signal strength were measured using spectrum analyzer as explained above.

Signal losses were calculated as follows (ITU-R, 2017)

$$A(dB) = KR^{\alpha} L_{eff} \qquad (7)$$

With $L_{eff} = rl$ (8)

Where l(km) is the actual path length, L_{eff} is the effective path length and r is a reduction coefficient given by (ITU-R, 2017)

$$r = \frac{1}{1 + CL^{m}} \qquad (9)$$

The signal loss A(dB) and the 1 minute rain rate R (mm/h) were calculated for the same time percentage (p); k and α are the regression coefficients depending on frequency (12.52 GHz) and polarization (Horizontal). C and m were derived using the experimental data obtained from the microwave channel at 12.52GHz band range with path length of 20km. It was found that C depends on probability level p (in percentage) of interest for which data are measured, and m depends on the radio channel path length and its frequency. The resultant formula for the path length reduction factor is given by (ITU-R, 2017)

$$r = \frac{1}{1 + 0.03\left(\frac{p}{0.01}\right)^{-\beta lm}} \qquad (10)$$

$$m(f, l) = 1 + \varphi(f) \log_{e} l \qquad (11)$$

$$\varphi(f) = 1.4 \times 10^{-4} f^{1.76} \qquad (12)$$

Where f is the frequency in GHz and the β coefficient is given based on (ITU-R, 2017)

When $l < 50km$

$\beta = 0.45, for\ 0.001 \leq p \leq 0.01$

$\beta = 0.6, for\ 0.01 \leq p \leq 0.1$

When $l \geq 50km$

$\beta = 0.36, for\ 0.001 \leq p \leq 0.01$

$\beta = 0.6, for\ 0.01 \leq p \leq 0.1$

For example

Using F =12.5GHz, equation (12) becomes

$\varphi(f) = 1.4 \times 10^{-4} 12.5^{1.76} = 0.013$

Putting the value of $\varphi(f)$ into equation (11)

$m(f,l) = 1 + 0.012.5 log_e l$

Where

$$log_e l = log_e 20 = \frac{\log_{10} 20}{\log e} = \frac{\log_{10} 20}{\log 2.71} = \frac{1.301}{0.432} = 3.011$$

$m(f,l) = 1 + 0.013 \times 3.011 = 1.039$

Putting the value of $m(f,l)$ into equation (10) for drizzle rain category either ≤5mm/hr at 2.979% for April 2021

$$r = \frac{1}{1 + 0.03\left(\frac{p}{0.01}\right)^{-\beta lm}} = \frac{1}{1 + 0.03\left(\frac{2.979}{0.01}\right)^{-0.45 \times 20 \times 1.039}} = 1.052$$

Putting the value of r into equation (8)

$L_{eff} = 1.052 \times 20 = 21.04$

Putting the value of L_{eff} into equation (7)

$A(dB) = 0.0341 \times (5)^{1.1586} \times 21.04 = 3.358$

Equation (7) to (12) was repeated for all the months and other rain categories (widespread, shower and thunderstorm).

RESULTS AND DISCUSSIONS

Table 1: Computation of Signal strength, BER and Signal losses for April 2021

Rain Category	Rain Duration (hour)	BER	Signal Strength (%)	Signal Losses (dB)
Drizzle (≤5mm/hr)	14.8	1.00E-06	70	3.358
Widespread (>5≤25mm/hr)	5.0	1.00E-08	62	23.291
Shower (>25≤50mm/hr)	0.8	1.00E-09	51	56.519
Thunder (>50mm/hr)	0.9	1.00E-07	67	17.656

Table 2: Computation of Signal strength, BER and Signal losses for May 2021

Rain Category	Rain Duration (hour)	BER	Signal Strength (%)	Signal Losses (dB)
Drizzle (≤5)	25.9	1.00E-07	67	3.324
Widespread (>5≤25)	7.2	1.00E-08	62	22.918
Shower (>25≤50)	1.6	1.00E-09	50	54.032
Thunder (>50)	2.4	1.00E-08	62	21.011

Table 3: Computation of Signal strength, BER and Signal losses for June 2021

Rain Category	Rain Duration (hour)	BER	Signal Strength (%)	Signal Losses (dB)
Drizzle (≤5)	19.8	1.00E-07	64	3.34
Widespread (>5≤25)	6.1	1.00E-08	52	23.20
Shower (>25≤50)	0.8	1.00E-09	45	57.35

Thunder (>50)	0.6	1.00E-09	42	114.91

Table 4: Computation of Signal strength, BER and Signal losses for July 2021

Rain Category	Rain Duration (hour)	BER	Signal Strength (%)	Signal Losses (dB)
Drizzle (≤5)	89.3	1.00E-06	76	1.787
Widespread (>5≤25)	19.7	1.00E-09	45	56.840
Shower (>25≤50)	5.6	1.00E-09	42	77.677
Thunder (>50)	4.2	1.00E-09	40	107.883

Table 5: Computation of Signal strength, BER and Signal losses for August 2021

Rain Category	Rain Duration (hour)	BER	Signal Strength (%)	Signal Losses (dB)
Drizzle (≤5)	24.3	1.00E-07	69	2.533
Widespread (>5≤25)	22.8	1.00E-09	44	44.692
Shower (>25≤50)	6.6	1.00E-09	41	64.322
Thunder (>50)	5.6	1.00E-09	39	106.600

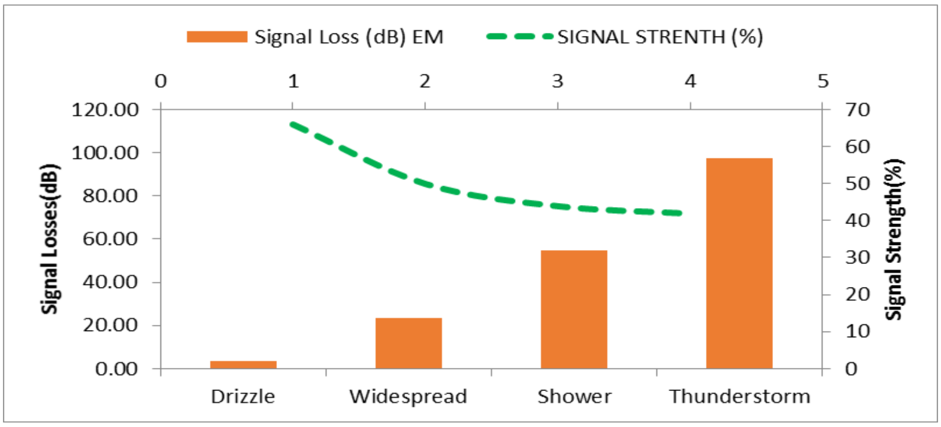

Figure 2. Variation of Rain type, Signal strength and losses for September 2021

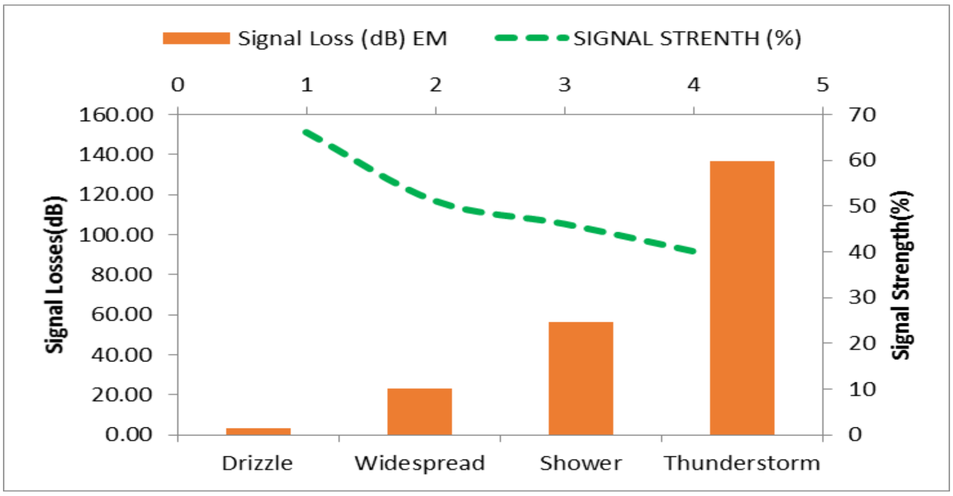

Figure 3. Variation of Rain type, Signal strength and losses for October 2021

Table 2 presents the computation of Signal strength, BER and Signal losses for April 2021. From the result obtained, shower (>25≤50) recorded the highest signal losses of 56.519dB and low signal strength of 51% with a BER of 10^{-9} while drizzle, widespread and thunderstorm recorded higher signal strength with BER less than 10^{-9} . Table 3 presents the computation of Signal strength, BER and Signal losses for May 2021. From the result obtained, shower (>25≤50) recorded the highest signal losses of 54.032dB and low signal strength of 50% with a BER of 10^{-9} while drizzle, widespread and thunderstorm recorded higher signal strength with BER less than 10^{-9}. Table 3 presents the computation of Signal strength, BER and Signal losses for June 2021. From the result obtained, thunder (>50) and shower (>25≤50) recorded the highest signal losses of 114.91dB and 57.35dB with low signal strength of 42% and 45% respectively and BER of 10^{-9} while drizzle and widespread recorded higher signal strength with BER less than 10^{-9}. Table 4 presents the computation of Signal strength, BER and Signal losses for July 2021. From the result obtained, thunder (>50) and shower (>25≤50) recorded the highest signal losses of 107.883dB and 77.677dB with low signal strength of 40% and 42% respectively and BER of 10^{-9} while drizzle and widespread recorded higher signal strength with BER less than 10^{-9} . Table 5 presents the computation of Signal strength, BER and Signal losses for August 2021. From the result obtained, thunder (>50) and shower (>25≤50) recorded the highest signal losses of 106.60dB and 64.32dB with low signal strength of 39% and 41% respectively and BER of 10^{-9} while drizzle and widespread recorded higher signal strength with BER less than 10^{-9}

Figure 2 and figure 3 present the variation of rain category, signal strength and losses for the months of September and October 2021. The results revealed that as a particular rain category become more severe or higher, the signal losses at that particular point also increase therefore affecting the level of signal strength to drop.

CONCLUSION

This study categorized rainfall rates into Drizzle (≤5mm/hr), Widespread (>5≤25mm/hr), Shower (>25≤50mm/hr) and Thunder (>50mm/hr). The results obtained revealed that the impact of drizzle (≤5mm/hr) on the radio link is not significant regardless the duration of rainfall. The results also revealed that severe signal losses recorded under shower (>25≤50mm/hr) and thunderstorm (>50mm/hr) were due to a greater value of BER ($\geq 10^{-9}$) which affected and reduced the level of the received signal as such limiting the performance of the satellite link under rain. This is because, for a satisfactory performance of the radio link under rain, the BER has to be less than 10^{-9}as recommended by ITU-R. The results further revealed that widespread (>5≤25mm/hr) that prevailed for a longer period also causes severe signal losses. This is to say that lower rain rate of about 25mm/hr that prevailed for a very long time have significant effect on the propagated signal.

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