Original Research Article

MODELLING OF THE RAIN RATE AND RAIN ATTENUATION FOR THE DESIGN OF LINE-OF-SIGHT LINK BUDGET OVER WARRI, DELTA STATE

ABSTRACT

This paper presents the modeling of the rain rate and rain attenuation for the design of line-of-sight link budget. Rain rate data were collected from the Nigeria Meteorological Agency (NIMET) for Warri, Delta State (5.554^0N 5.793^0E). The rain rate data were collect for the period of two years (2018 and 2019).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. It is able to measure rainfall intensity from a minimum of 0.8 mm/h up to a value of 460 mm/h, with an accuracy of 0.2 mm/h. Cumulative distributions of rain rate values computed from the data obtained shows that the effect of rain attenuation on Line of Sight is more severe from rain rate of 50mm/hr at CDF of 0.0176%. As seen from the results, 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.

Keywords: Rain rate, Attenuation, Line-of-Sight, Link Budget

1.0 INTRODUCTION

With the increasing demand of bandwidth, a wide range of application of satellite communication system. Communication satellite above 10GHZ namely; Ku–and Ka -band and above are currently used with several merits such as reduced equipment size and interference avoidance with terrestrial microwave communication systems. However, the earth space propagation above 10GHZ is highly susceptible to propagation impairment like rain attenuation and depolarization. Tropospheric propagation characteristics relate to radio communication above 10GHZ can be classified into three type: rain attenuation, scintillation and depolarization (Animesh *et al.,* 2012).

Rain attenuation prediction is one of the important steps to consider when evaluating a satellite communication links.The intensity of rainfall along terrestrial path is inhomogeneous, rain have a non-spherical shape thus causes the attenuation on the horizontally polarized wave to be greater than the attenuation of the vertically polarized waves. Rain is the major parameter in the design of terrestrial and microwave satellite link budgets. Attenuation due to rain depends on frequency and the rainfall rate.Rainfall is a major cause of signal degradation for radio-communication systems operating at microwave bands, especially in the tropical region environment. Determination of attenuation due to rainfall plays a significant role in the design of earth-satellite radio link at frequencies above 10 GHz. Rain attenuation of satellite signals do not simply affect the end users' resulting performance, it also affects the cost. Rain attenuation causes a greater power requirement from the transmitting units which hence lead to a higher cost per bit of transmission (Aderemi et al, 2011).

The variation in rainfall rate is given as a probabilistic value which is often expressed as a rainfall rate exceeded for a certain percentage of the time. For a precise satellite link budget, all the parameters are needed to be analyzed in order to develop a model that helps find the nearest possible attenuation under the required given time. Attenuation experienced in Warri Delta State is caused by considerably higher rainfall intensity compared to other parts of the country.

The concept of rain attenuation follows the relationship of frequency and wavelength either frequency is inversely proportional to the wavelength,

$$C = \lambda f \tag{1}$$

Where λ is the wavelength, F is the frequency and C is the speed of light ($3x10^8$m/s). Now the attenuation increases as the wavelength approaches a typical raindrop size. The attenuation is small for S band and C band, but as the frequency gets higher and so the wavelength approaches to a raindrop size, attenuation increases. Attenuation is high at Ku band and significant for K band and Ka band. (Aderemi et al, 2011).

The method for the prediction of rain attenuation on LOS paths are grouped into two:

i. The empirical method based on measurement databases from stations in different climatic zones within a given region and
ii. The physical method that makes an attempt to reproduce the physical behavior involved in the attenuation process.For the empirical methodology, an appropriate distribution of rainfall rate at 1-minute integration time was used for the site under studied in order to predict accurate rain attenuation for the location (Bryant et al, 2001).

The radio link budget sums the transmitted power along with the gains and losses to determine the signal strength arriving at the receiver input. In essence the link budget will take the form of the equation below

$$\text{Received power (dBm)} = \text{Transmitted power (dBm)} + \text{Gains (dB)} - \text{Losses (dB)} \quad (2)$$

It is necessary to investigate all the areas where gains and losses may occur between the transmitter and the receiver. Below is a typical link budget equation for a radio communications system

$$PRX = PTX+GTX+GRX-LTX-LFS-LP-LRX \quad (3)$$

Where:

PRX = received power (dBm)
PTX = transmitter output power (dBm)
GTX = transmitter antenna gains (dBi)
GRX = receiver antenna gains (dBi)
LTX = transmit feeder and associated losses (feeder, connectors, etc.) (dB)
LFS = free space loss or path loss (dB)
LP = miscellaneous signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)
LRX = receiver feeder and associated losses (feeder, connectors, etc.) (dB)

Rainfall rate is a measure of the amount of rain precipitation over a given time $(mmhr^{-1})$ and is a function of the raindrop size distribution. Rainfall rate, as given by Baltas, *et al.* (2002), can be defined by the following:

$$R = \frac{3.6}{10^3} \times \frac{\pi}{6} \times \int_0^{\infty} v(D) D^3 \, N(D) dD \qquad (4)$$

where R is the rainfall rate, v(D) is the fall velocity of the drop at diameter D and N(D) is the raindrop size distribution.

Rainfall rate is proportional to the moment of N(D, t), the measured DSD at the discrete instant t (time in seconds), of order 3.67,Montopoli *et al.,* (2008). The fall velocity (v(D)) may be assumed to be v(D) = $3.78 \times D^{O.67}$.

$$M_n(t) = \int_0^{\infty} D^n \times N(D,t) \times dD = \sum_{i=1}^{n_c} D_i^n \times N_M \; (D_i, t) \times \Delta D_i \qquad (5)$$

The following equation shows rainfall rate proportional to the moment of the raindropsize distribution of order 3.67:

$$R = 3.78 \times \frac{\pi}{6} \times \; M_{3.67}(t) \qquad (6)$$

Rainfall rate can be measured over different time intervals. During a long time interval (an hour or more) a rain event may change considerably. Measuring rainfall rate over such a long time period effectively averages the rainfall rate. Small time intervals (such as 1 minute) will represent more changes in the rain event.

2.0 METHODOLOGY

Rain rate data were collected from the Nigeria Meteorological Agency (NIMET) for Warri, Delta State (5.554^0N 5.793^0E). The rain rate data were collect for the period of two years (2018 and 2019).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 intensity from a minimum of 0.8 mm/h up to a value of 460 mm/h, with an accuracy of 0.2 mm/h. The precipitation data, with date and time is captured on the micro-chip of the wireless electronic data logger, which, when calibrated, logs on data every minute. The microchip has storage capacity of about 2563 pages, each page stands for one record, after which (i.e. after 42hours) the memory overwrites and recorded data is lost if not harvested. Technically, the data logger is connected to a Personal computer to harvest the data on a daily basis to prevent data loss.

The long-term behavior of rain fall rate is described by a cumulative distribution function (CDF). The CDF for rainfall rate is commonly referred to as an exceedance curve. This gives a percentage of time (usually the percent of 1 year) that the rain fall rate exceeds a given value. Climate related parameters tend to be very variable. Rain accumulation can vary significantly from year-to-year, as can the exceedance curves, particularly at the low time percentages of interest to communication link designers. The CDF using rainfall rate was obtained using the following steps:

1. The frequency of each rain rate (mm/hr) recorded at one minute integration time for each of the month and year under review was obtained
2. The cumulative frequency (N) was calculated from the rain rate frequency
3. The cumulative distribution function (CDF) for each of the month was calculated using

   $CDF = \frac{N \times 100\%}{30 \times 24 \times 60}$, (for months with 30days) (7a)

   $CDF = \frac{N \times 100\%}{31 \times 24 \times 60}$, (for months with 31days) (7b)

In computing the effect of rain attenuation on line of sight link, ITU-R rain attenuation model and Moupfouma rain attenuation model were used.

ITU-R Rain Attenuation Model:

Step 1: The rain rate $R_{0.01}$ exceeded for 0.01% of the time (with an integration time of 1 min) was obtained for each of the month and year under study (ITU-R, 2015)

Step 2: The specific attenuation, γ_R (dB/km) for the frequency, polarization and rain rate of interest was computed as

$$\gamma = kR^{\alpha}(dB/km) \quad (8)$$

Where R is rainfall rate in mm/hr, the coefficients *k* and α were determined as a function of frequency where *k* =0.03041 and α = 1.1586 as given by ITU-R for horizontal polarization at frequency of 13 GHz.

For example, at rain rate of 5mm/hr, $\gamma_R = 0.03041(5)^{1.1586} = 0.196\, dB/km$ and at rain rate of 140mm/hr, $\gamma_R = 0.03041(140)^{1.1586} = 9.322\, dB/km$

Step 3: The effective path length d_{eff} of the link was computed by multiplying the actual path length *d(20km)* by a distance factor *r*.

$$d_{eff} = dr \quad (9)$$

An estimate of this factor is given by:

$$r = \frac{1}{1 + d/d_0} \quad (10)$$

Where, for $R_{0.01} \leq 100$ mm/h:

$$d_0 = 35\, e^{-0.015R_{0.01}} \quad (11)$$

For $R_{0.01}$>100 mm/h, the value 100 mm/h was used in place of $R_{0.01}$.

At rain rate of 5mm/hr

$d_0 = 35 \times e^{-0.015(5)} = 32.471,\ r = \frac{1}{1+ {}^{20}/_{32.471}} = 0.619$

Therefore, $d_{eff} = 20 \times 0.619 = 12.377km$

Step 4: An estimate of the path attenuation exceeded for 0.01% of the time is given by:

$$A_{0.01} = \gamma_R\, d_{eff} = \gamma_R\, dr \quad \text{dB} \tag{12}$$

At rain rate of 5mm/hr

$$A_{0.01} = 0.196 \times 12.377 = 2.429dB$$

Step 5: The attenuation exceeded for other percentages of time *p* in the range 0.001% to 1% was deduced from the following power law:

$$\frac{A_p}{A_{0.01}} = 0.07\, p^{-(0.855\ +\ 0.139 \log_{10} p)} \tag{13}$$

For rain rate of 5mm/hr,

$$A_p = 0.07 \times 3.303 \times 2.429^{-(0.855+0.139Log3.303)} = 0.056dB$$

Step 1 to 5 was repeated for the entire rain rate for the months and years under study and the attenuation (Ap) were obtained.

Moupfouma rain attenuation model

Moupfouma proposed an empirical model for predicting the effect of rain attenuation on terrestrial paths from the knowledge of 1 min rain rate recorded.

$$A(dB) = KR^{\propto}L_{eff} \tag{14}$$

With $L_{eff} = rl$ (15)

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

$$r = \frac{1}{1+CL^m} \tag{16}$$

The attenuation A (dB) and the 1 min rain rate R (mm/h) are calculated for the same time percentage; k and α are the regression coefficients depending on frequency and polarization. C and m were derived using the experimental data obtained from the terrestrial radio links in the 13GHz band range with path length of 20km. It was found that C depends on probability level Ƥ (in percentage) of interest for which data are available, and m depends on the radio link path length and its frequency. The resultant formula for the path length reduction factor is given by

$$r = \frac{1}{1+0.03(\frac{p}{0.01})^{-\beta l m}} \quad (17)$$

$$m(f,l) = 1 + \varphi(f) log_e l \quad (18)$$

$$\varphi(f) = 1.4 \times 10^{-4} f^{1.76} \quad (19)$$

Where f is the frequency in GHz and the β coefficient is given based on

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 =13GHz, equation (19) becomes

$$\varphi(f) = 1.4 \times 10^{-4} 13^{1.76} = 0.013$$

Putting the value of $\varphi(f)$ into equation (18)

$m(f,l) = 1 + 0.013 log_e l$

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 (17) for rain rate of 5mm/hr at 3.303% for April 2019,

$$r = \frac{1}{1 + 0.03(\frac{p}{0.01})^{-\beta lm}} = \frac{1}{1 + 0.03(\frac{3.303}{0.01})^{-0.45\times20\times1.039}} = 1.05$$

For rain rate of 140mm/hr at 0.005%

$$r = \frac{1}{1 + 0.03(\frac{0.005}{0.01})^{-0.45\times20\times1.039}} = 1.95$$

Putting the value of r into equation (15)

At rain rate of 5mm/hr

$$L_{eff} = 1.05 \times 20 = 20.99$$

At rain rate of 140mm/hr

$$L_{eff} = 1.95 \times 20 = 39.03$$

Putting the value of L_{eff} into equation (14)

At rain rate of 5mm/hr

$$A(dB) = 0.0341 \times (5)^{1.1586} \times 20.99 = 4.62\ dB$$

At rain rate of 140mm/hr

$$A(dB) = 0.0341 \times (140)^{1.1586} \times 39.03 = 408.03\ dB$$

Equation (14) to (19) was repeated for the entire rain rate.

3.0 RESULTS

Table 1: Determination of CDF and effect of rain attenuation on Line of Sight for April 2018

Rain Rate (mm/hr)	Frequency of Rain rate	Cumulative Freq. of Rain Rate (N)	CDF (%)	Rain Attenuation (dB) Using ITU-R Model	Rain Attenuation (dB) Using Moupfouma Model
5	1025	1427	3.303	0.056	4.62
10	193	402	0.931	0.392	10.69

20	85	209	0.484	1.393	24.51
30	30	124	0.287	3.057	40.30
40	18	94	0.218	4.794	57.21
50	22	76	0.176	6.597	75.16
60	21	54	0.125	9.266	95.25
70	10	33	0.076	13.428	118.89
80	5	23	0.053	17.204	143.98
90	5	18	0.042	20.086	169.67
100	6	13	0.030	23.654	199.61
120	5	7	0.016	29.803	269.58
140	2	2	0.005	39.884	408.03

Table 2: Determination of CDF and effect of rain attenuation on Line of Sight for June 2018

Rain Rate (mm/hr)	Frequency of Rain rate	Cumulative Freq. of Rain Rate (N)	CDF (%)	Rain Attenuation (dB) Using ITU-R Model	Rain Attenuation (dB) Using Moupfouma Model
5	2792	3556	8.231	0.021	4.546
10	338	764	1.769	0.222	10.470
20	184	426	0.986	0.782	23.806
30	79	242	0.560	1.858	38.948
40	53	163	0.377	3.254	55.403
50	40	110	0.255	5.154	73.361

60	29	70	0.162	7.890	93.386
70	12	41	0.095	11.898	116.545
80	13	29	0.067	15.268	140.551
90	5	16	0.037	21.215	172.086
100	4	11	0.025	25.381	204.136
120	4	7	0.016	29.803	269.580
140	3	3	0.007	36.325	374.848

Table 3: Determination of CDF and effect of rain attenuation on Line of Sight for July 2018

Rain Rate (mm/hr)	**Frequency of Rain rate**	**Cumulative Freq. of Rain Rate (N)**	**CDF (%)**	**Rain Attenuation (dB) Using ITU-R Model**	**Rain Attenuation (dB) Using Moupfouma Model**
5	4608	5922	13.278	0.012	4.518
10	556	1314	2.946	0.136	10.338
20	274	758	1.700	0.483	23.400
30	159	484	1.085	1.077	37.955
40	97	325	0.729	1.951	53.754
50	82	228	0.511	3.094	70.684
60	55	146	0.327	4.899	89.303
70	43	91	0.204	7.420	109.874

80	21	48	0.108	11.736	134.575
90	13	27	0.061	16.702	162.806
100	2	14	0.031	23.224	198.513
120	4	12	0.027	24.482	250.256
140	7	8	0.018	27.010	317.231
160	1	1	0.002	40.656	565.904

Table 4: Determination of CDF and effect of rain attenuation on Line of Sight for August 2018

Rain Rate (mm/hr)	**Frequency of Rain rate**	**Cumulative Freq. of Rain Rate (N)**	**CDF (%)**	**Rain Attenuation (dB) Using ITU-R Model**	**Rain Attenuation (dB) Using Moupfouma Model**
5	4316	5329	11.948	0.014	4.524
10	512	1013	2.271	0.176	10.402
20	182	501	1.123	0.699	23.700
30	98	319	0.715	1.528	38.546
40	69	221	0.496	2.650	54.660
50	55	152	0.341	4.193	72.139
60	39	97	0.217	6.510	91.519
70	15	58	0.130	9.881	113.520
80	14	43	0.096	12.508	135.857
90	8	29	0.065	16.092	161.619
100	6	21	0.047	19.260	189.017

120	9	15	0.034	22.232	243.055
140	1	6	0.013	29.890	332.181
160	3	5	0.011	28.734	400.049
180	2	2	0.004	32.028	549.793

Table 5: Determination of CDF and effect of rain attenuation on Line of Sight for September 2018

Rain Rate (mm/hr)	**Frequency of Rain rate**	**Cumulative Freq. of Rain Rate (N)**	**CDF (%)**	**Rain Attenuation (dB) Using ITU-R Model**	**Rain Attenuation (dB) Using Moupfouma Model**
5	3079	3903	9.035	0.019	4.540
10	398	824	1.907	0.207	10.449
20	150	426	0.986	0.782	23.806
30	74	276	0.639	1.674	38.726
40	65	202	0.468	2.770	54.811
50	40	137	0.317	4.417	72.426
60	29	97	0.225	6.372	91.331
70	28	68	0.157	8.777	111.884
80	5	40	0.093	12.800	136.344
90	7	35	0.081	14.295	158.197
100	9	28	0.065	16.387	182.662
120	10	19	0.044	19.642	235.301
140	1	9	0.021	25.522	310.186
160	8	8	0.019	24.188	368.511

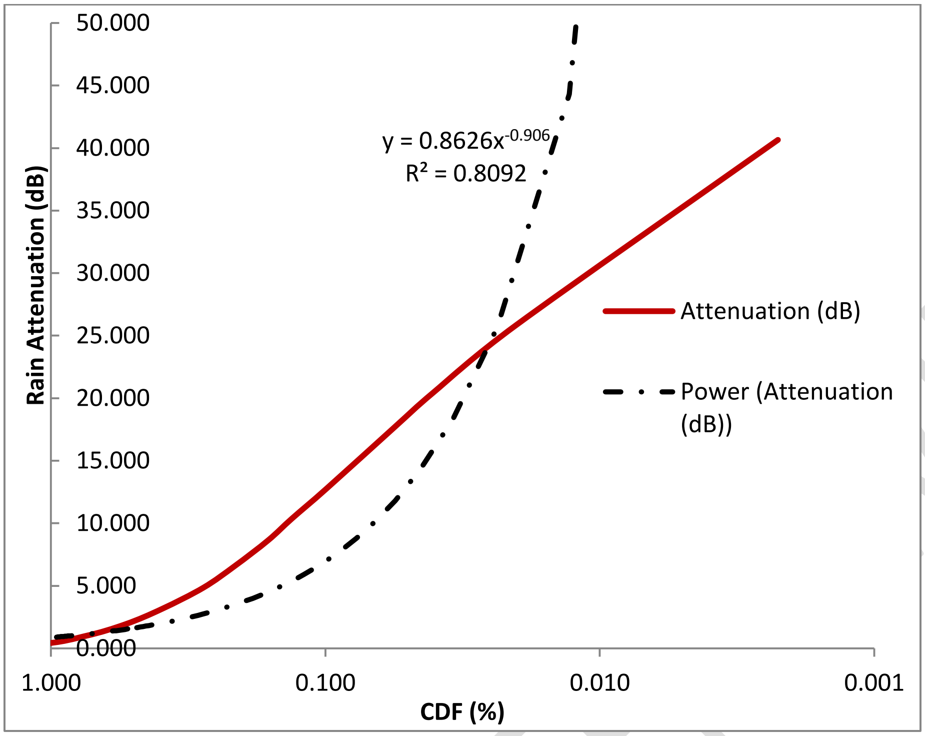

Figure 1: Relationship between CDF and rain attenuation for May 2019.

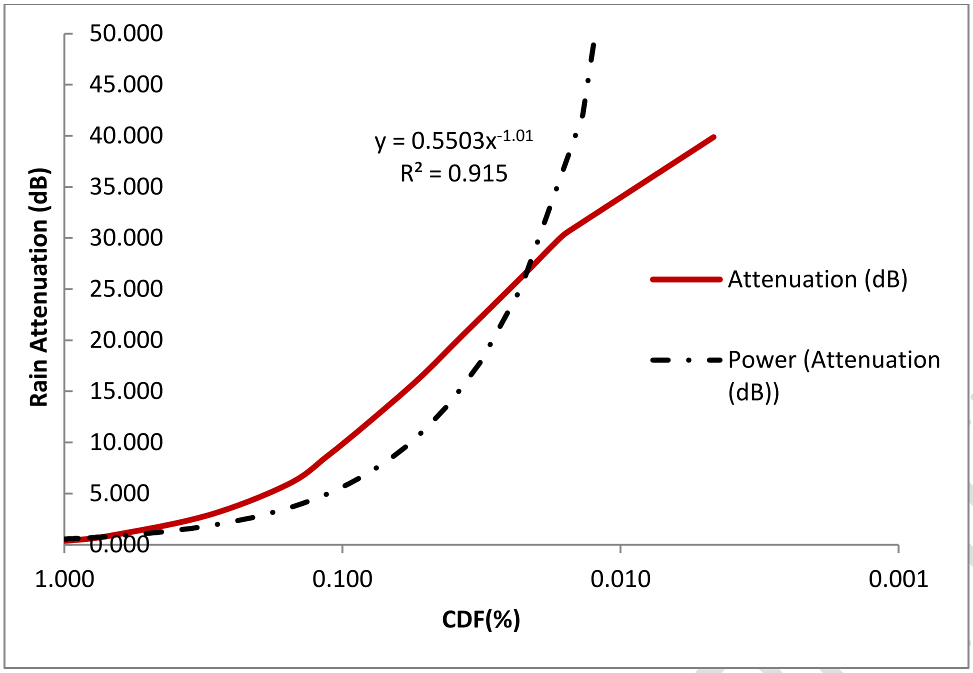

Figure 2: Relationship between CDF and rain attenuation for June 2019.

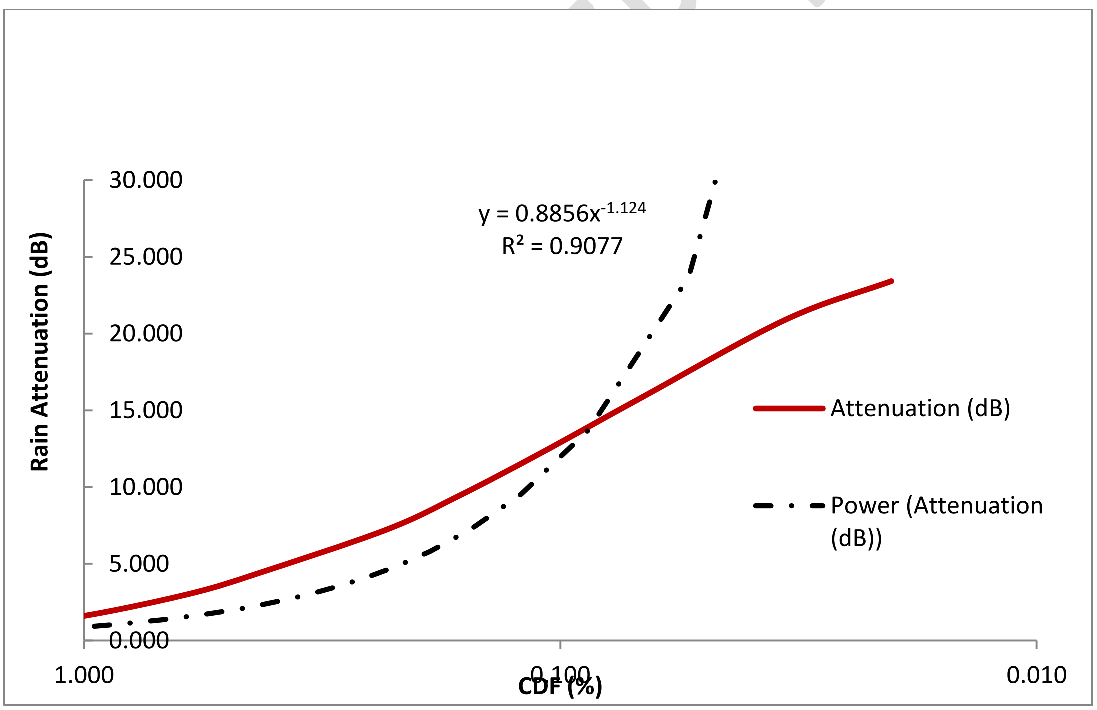

Figure 3: Relationship between CDF and rain attenuation for July 2019.

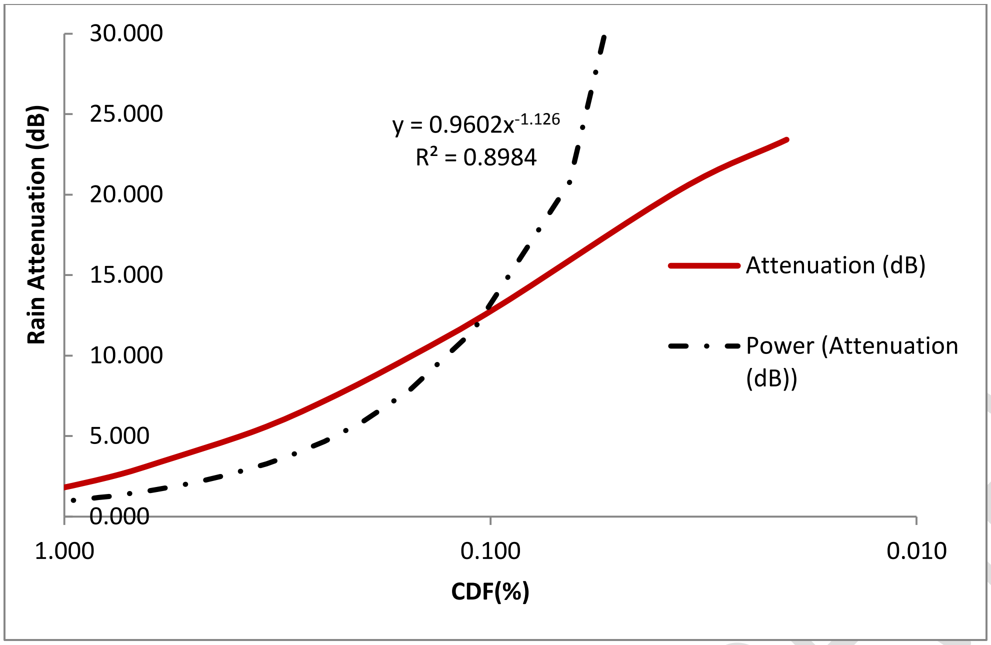

Figure 4: Relationship between CDF and rain attenuation for August 2019.

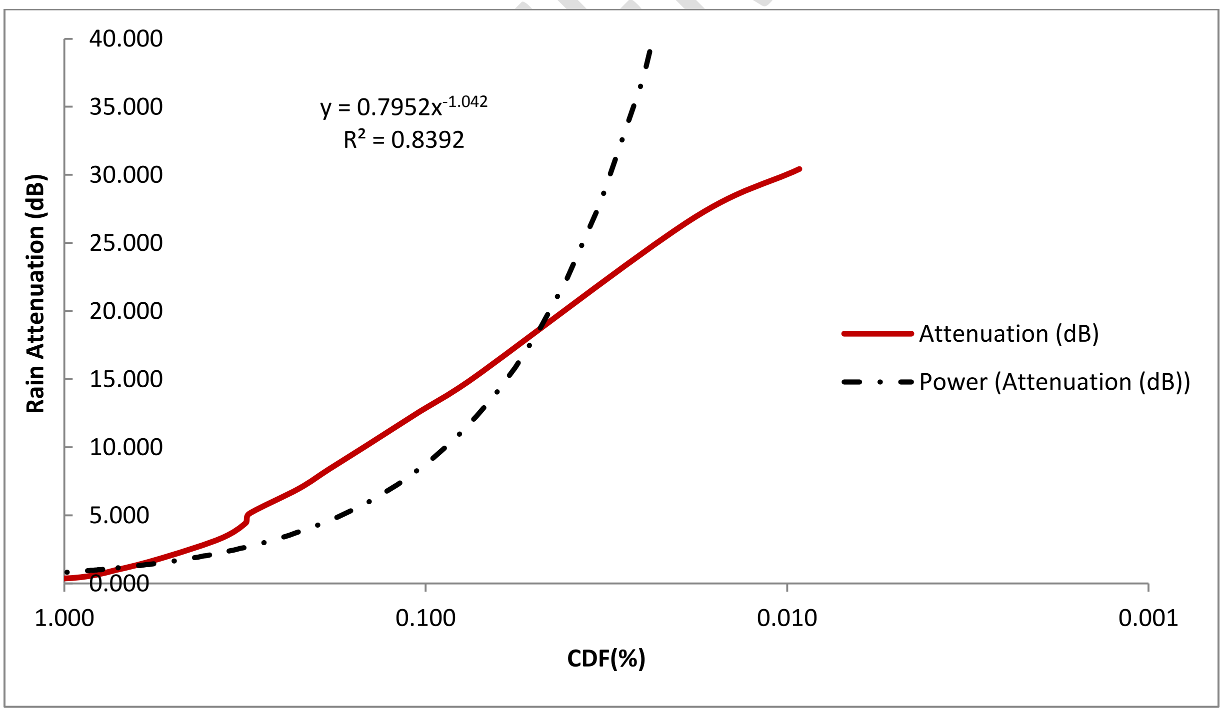

Figure 5: Relationship between CDF and rain attenuation for September 2019.

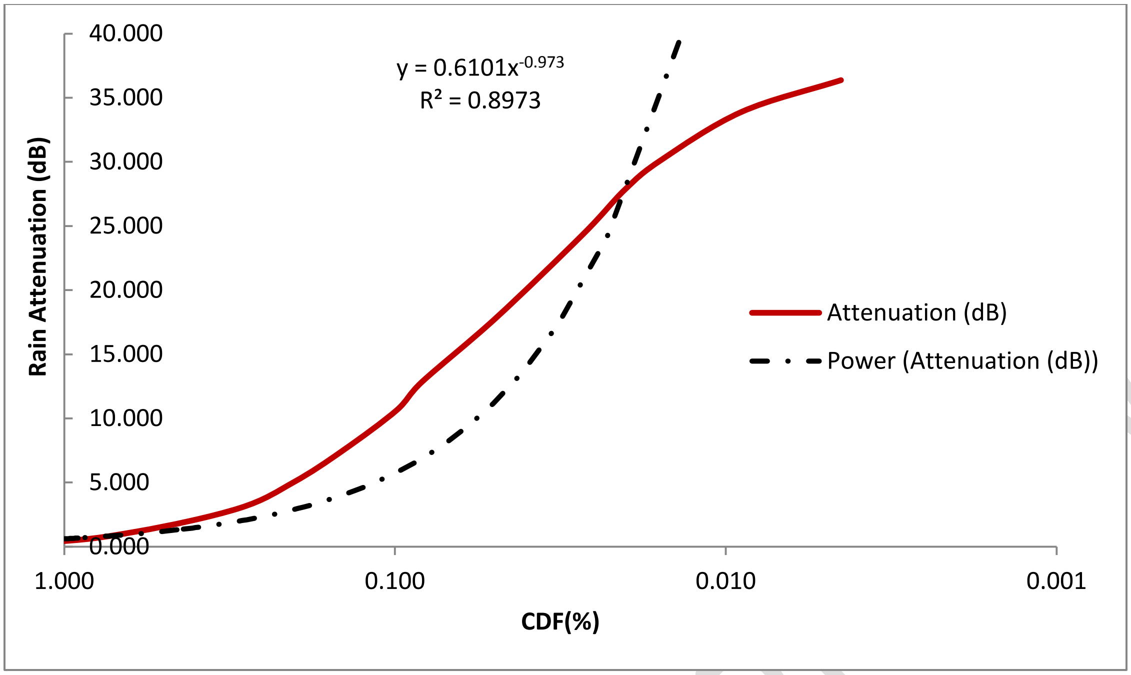

Figure 6: Relationship between CDF and rain attenuation for October 2019.

4. DISCUSSION

Table 1 presents the determination of Rain rate, CDF and effect of rain attenuation on Line of Sight for April 2018. The result shows that the effect of rain attenuation on Line of Sight is more severe from rain rate of 50mm/hr at CDF of 0.0176% with attenuations of 6.597dB using ITU-R model and 75.16dB using Moupfouma model.

Table 2 presents the determination of CDF and effect of rain attenuation on Line of Sight for June 2018. The result shows that the effect of rain attenuation on Line of Sight for the month of June is more severe from rain rate of 80mm/hr at CDF of 0.067% with attenuations of 15.268dB using ITU-R model and 140.551dB using Moupfouma model.

Table 3 presents the determination of CDF and effect of rain attenuation on Line of Sight for July 2018. The result shows that the effect of rain attenuation on Line of Sight for the month of July is more severe from rain rate of 80mm/hr at CDF of 0.108% with attenuations of 11.736dB using ITU-R model and 134.575dB using Moupfouma model.

Table 4 presents the determination of CDF and effect of rain attenuation on Line of Sight for August 2018. The result shows that the effect of rain attenuation on Line of

Sight for the month of August is more severe from rain rate of 80mm/hr at CDF of 0.096% with attenuations of 12.5086dB using ITU-R model and 135.857dB using Moupfouma model.

Table 5 presents the determination of CDF and effect of rain attenuation on Line of Sight for September 2018. The result shows that the effect of rain attenuation on Line of Sight for the month of September is more severe from rain rate of 100mm/hr at CDF of 0.065% with attenuations of 16.3876dB using ITU-R model and 182.662dB using Moupfouma model.

Figure 1 to 6 presents the relationship between CDF and rain attenuation for the year 2019 which clearly shows that rain attenuation increases from CDF of 0.1% to 0.00%.

5.0 CONCLUSIONS

The rain rate and rain attenuation parameters were examined for Warri Delta State using two years data from Nigeria Meteorological Agency (NIMET). Cumulative distributions of rain rate values computed from the data obtained shows that the effect of rain attenuation on Line of Sight is more severe from rain rate of 50mm/hr at CDF of 0.0176%. As seen from the results, 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.

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