EVALUATION OF PROPAGATION LOSSES DUE TO RAIN ATTENUATED SIGNAL ON TERRESTRIAL RADIO LINKS OVER JOS, PLATEAU STATE NIGERIA.

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ABSTRACT

This paper presents the evaluation of propagation losses due to rain attenuated signal on terrestrial radio link. Rain rate data were measured using Davis weather station for the months of July, August and October 2017 at (9.9565° N, 8.8583° E; 1258 meters) Jos Plateau state Nigeria. The data were analyzed using Microsoft Excel application package. Results were calculated based ITU-Recommendation. The result for the month of July shows that rain attenuated signals become more severe from rain rate of 90mm/hr at 0.014% to 160mm/hr at 0.002% with attenuation of 31.215dB and 105.951dB respectively. Also, the month of August shows that rain attenuated signals become more severe from rain rate of 70mm/hr at 0.017% to 200mm/hr at 0.002% with attenuation of 69.509dB and 108.324dB respectively. Furthermore, the month of October shows that rain attenuated signals become more severe from rain rate of 70mm/hr at 0.014% to 160mm/hr at 0.004 with attenuation of 50.301dB and 135.336dB respectively. Therefore, results from this study revealed that rain attenuated signals on terrestrial radio links in tropical Nigeria is more severe at higher rainfall rate (above 60mm/hr) and lower exceeded frequency percentage of time (0.01% to 0.001%).

Keyword: Terrestrial radio link, Propagation, Rain attenuation and Rain rate

1.0 INTRODUCTION

Radio communication uses electromagnetic wave propagated through the earth's atmosphere or space to carry information over long distance without use of wires. Radio wave with frequencies ranging about 100Hz in the extremely low frequency (ELF) band to well above 300 GHz in the extremely high frequency (EHF) band are used for communication purposes [6].

Terrestrial radio links generally use line-of-sight (LOS). The maximum distance between two stations depends on the height of the transmitting and receiving antennas as well as one the nature of the terrain between them. For average atmospheric conditions and level terrain, the distance over which line-of-sight is possible given by [2]

$$d = \sqrt{17h_r} + \sqrt{17h_g} \quad (1)$$

Where

d = Maximum distance in kilometers

h_r= height of the transmitting antenna in meters

h_g= height of the receiving antenna in meters.

Point-to-point microwave radio links have many uses. They can be used as studio-to-transmitter (STL) links for radio and television broadcasting stations. Another very common application of microwave links is a part of a communications network involves telephone, data, or television signals. There is no doubt that terrestrial microwave systems will continue to be part of the evolving communications grid. Some microwave system use only one link or hop, while others are multihop systems that use repeaters to extend the system beyond the line-of-sight range [2].

Radio links operating at frequencies above 10 GHz are subject to severe propagation losses cause mostly by rainfall. The propagation losses due to rain particles is non-uniform and can only be statistically or experimentally determined from the rain rate measurements. The consequences of this rain attenuation are as follows [3]:

i. Loss of signal strength at the receiver.
ii. Wastage of transmission power in a bid to overcome this form of attenuation.
iii. Total loss of signal at the receiver in extreme cases.
iv. Unavailability of the satellite link for a great percentage of the time

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 [5]. Rain attenuation of radio 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 [3].

The strength of propagated signal may be degraded or reduced under rain conditions. Most especially, radio waves above 10 GHz are subject to attenuation by molecular absorption and rain. Presence of rain drops can severely degrade the reliability and performance of communication links. Losses due to rain effect is a function of various parameters including elevation angle, carrier frequency, height of earth station, latitude of earth station and rain fall rate. The primary parameters are drop-size distribution and the number of drops that are present in the volume shared by the wave with the rain [7]

The propagation losses due to rain is given by

$$L = 10log\frac{P_o(0)}{P_r(r)} \quad (2)$$

Where P_o is the signal power before the rain region, P_r is the signal power after the rain region, r is the path length through the rain region [1].

The propagation loss due to rain is usually expressed by specific attenuation $\boldsymbol{\gamma}$ in decibel per kilometer. Therefore, propagation loss is

$$L = \boldsymbol{\gamma L_r} \quad (3)$$

Where $\boldsymbol{\gamma}$ is specific attenuation in dB/km and L_r is rain path length in km. base on ITU-R specific attenuation model, it is found that $\boldsymbol{\gamma}$ depends only on rainfall rate measured in millimeters per hour. From this model, the usual form of expressing $\boldsymbol{\gamma}$ is

$$\gamma = kR^{\alpha}(dB/km) \quad (4)$$

Where k and α are frequency dependent coefficients [1].

Propagation loss due to rain is a key limiting factor in using high frequency bands in satellite and terrestrial microwave energy. Very intense rain rate causes link outage if the rain drop size approaches half the wavelength of the signal in diameter.

2.0 MATERIALS AND METHODS

The equipment were setup at the experimental site located at a Nigeria's Telecoms Operator Switch Center (9.9565° N, 8.8583° E; 1258 meters) Jos Plateau state Nigeria. Data were obtained for the period of Three months (July, August, and October 2017). The equipment used includes the following: Davis weather station, USB data logger, computer system, Compass, Radio frequency power meter, Coaxial cable port connector and connecting cable (coaxial cable). The Davis Vantage Vue weather station is an 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 copied to an external memory device. Technically, the data logger is connected to a Personal computer to harvest the data on a daily basis to prevent data loss.

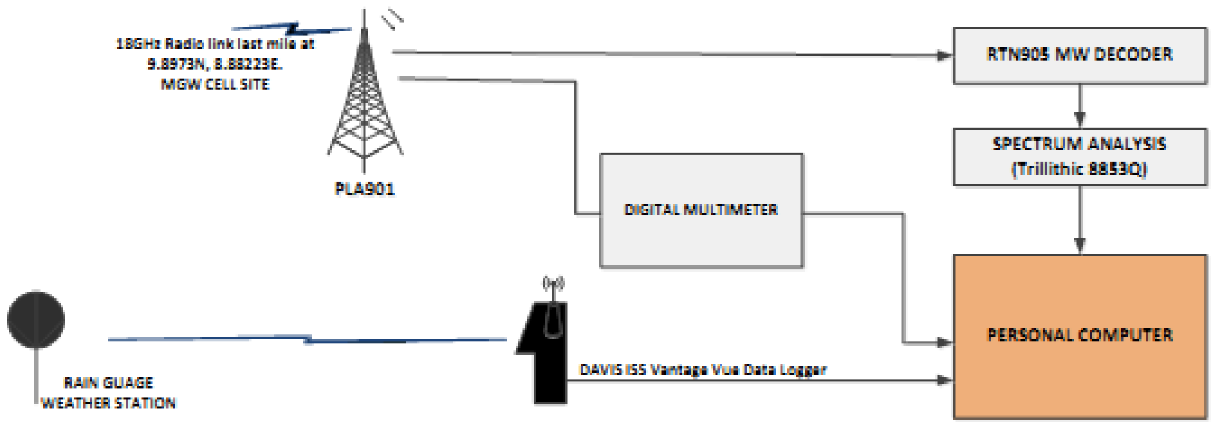

Figure 1: Experimental Setup

The International Telecommunication Union (ITU) recommendation P.530-9 was used to obtained the propagation losses due to rain attenuated signal on terrestrial radio links at Frequency of 13/18 GHz. For this study, Actual path length (d) 20km, Horizontal polarization was considered.

The procedures followed for calculating rain attenuated are:

Step 1: The rain rate $R_{0.01}$ exceeded for 0.01% of the time (with an integration time of 1 min) was obtained and presented in Table 1 to 3 for each of the month under study

Step 2: The specific attenuation, γ_R (dB/km) for the frequency, polarization and rain rate of interest was computed using Recommendation ITU-R P.838 as given in equation (4)

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. Equation (4) was used to obtained the specific attenuation for each rain rate (mm/hr) presented in Table 1 to 3. For example, at rain rate of 1mm/hr,

$$\gamma_R = 0.03041(1)^{1.1586} = 0.03041\ dB/km$$

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

$$d_{eff} = dr \tag{5}$$

An estimate of this factor is given by:

$$r = \frac{1}{1 + d/d_0} \qquad (6)$$

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

$$d_0 = 35\, e^{-0.015\, R_{0.01}} \qquad (7)$$

For example, for rain rate of 1mm/hr

$d_0 = 35 \times e^{-0.015(1)} = 34.47, \; r = \frac{1}{1+ {}^{20}/_{34.47}} = 0.629$

Therefore, $d_{eff} = 20 \times 0.629 = 12.65km$

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

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

$$A_{0.01} = \gamma_R\, d_{eff} = \gamma_R\, dr \quad \text{dB} \qquad (8)$$

At rain rate of 1mm/hr

$$A_{0.01} = 0.3041 \times 12.65 = 0.385dB$$

Step 5: For radio links located at latitudes below 30° (North or South), the attenuation exceeded for other percentages of time p in the range 0.001% to 1% may be deduced from the following power law:

$$\frac{A_p}{A_{0.01}} = 0.07\, p^{-(0.855 + 0.139 \log_{10} p)} \qquad (9)$$

For example, for rain rate of 1mm/hr,

$$A_p = 0.07 \times 0.385 \times 11.550^{-(0.855+0.139Log11.550)} = 0.002dB$$

Step 1 to 5 was repeated for all the rain rate and the Attenuation (Ap) are presented in table 1 to 3 for each of the month under study.

3.0 RESULTS

Table 1: July 2017 computation of propagation losses due to rain attenuated signal

Rain Rate (mm/hr)	Frequency	Commutative Freq.	Exceeded Freq. of % time = $\frac{N\times 100\%}{31\times 24\times 60}$	Rain Attenuation (dB)
1	2761	5156	11.550	0.002
2	786	2395	5.365	0.011
4	564	1609	3.604	0.039
6	432	1045	2.340	0.096
8	145	613	1.373	0.218
10	221	468	1.048	0.354
15	34	247	0.553	0.928
20	54	213	0.477	1.408
25	72	159	0.356	2.193
30	23	87	0.194	3.991
35	12	64	0.143	5.584
40	22	52	0.116	7.124
45	10	30	0.067	11.592
50	7	20	0.044	15.299
60	1	13	0.029	19.839
70	3	12	0.026	20.963
80	2	9	0.020	26.505
90	1	7	0.014	31.215
100	2	6	0.013	32.451
120	1	4	0.008	52.259
140	2	3	0.006	60.225
160	1	1	0.002	105.951

Table 2: August 2017 computation of propagation losses due to rain attenuated signal

Rain Rate (mm/hr)	**Frequency**	**Commutative Freq.**	**Exceeded Freq. of % time = $\frac{N\times100\%}{31\times24\times60}$**	**Rain Attenuation (dB)**
1	967	5671	12.703	0.002
2	1098	4704	10.537	0.006
4	1401	3606	8.077	0.016
6	693	2205	4.939	0.040
8	842	1512	3.387	0.079
10	220	670	1.500	0.216
15	109	450	1.008	0.489
20	89	341	0.763	0.849
25	65	252	0.564	1.408
30	100	187	0.418	2.218
35	25	87	0.194	5.191
40	40	62	0.138	7.982
45	7	22	0.049	22.676
50	4	15	0.033	37.584
60	3	11	0.024	53.359
70	1	8	0.017	69.509
80	0	7	0.014	72.482
90	2	7	0.014	74.156
100	1	5	0.011	80.426
120	0	4	0.008	89.310
140	0	4	0.008	94.222
160	1	4	0.008	98.465
180	2	3	0.006	100.900
200	1	1	0.002	108.324

Table 3: October 2017 computation of propagation losses due to rain attenuated signal

Rain Rate (mm/hr)	Frequency	Commutative Freq.	Exceeded Freq. of % time = $\frac{N \times 100\%}{31 \times 24 \times 60}$	Rain Attenuation (dB)
1	851	2716	6.084	0.004
2	900	1865	4.177	0.013
4	327	965	2.161	0.055
6	89	638	1.429	0.128
8	243	549	1.229	0.203
10	45	306	0.685	0.447
15	67	261	0.584	0.805
20	23	194	0.434	1.433
25	17	171	0.383	2.014
30	78	154	0.344	2.655
35	39	76	0.170	5.860
40	11	37	0.082	12.859
45	9	26	0.058	19.447
50	2	17	0.038	33.067
60	7	15	0.033	39.991
70	1	8	0.014	50.301
80	0	7	0.014	54.436
90	0	7	0.014	56.427
100	2	7	0.014	57.354
120	2	5	0.011	91.930
140	1	3	0.006	123.483
160	2	2	0.004	135.336

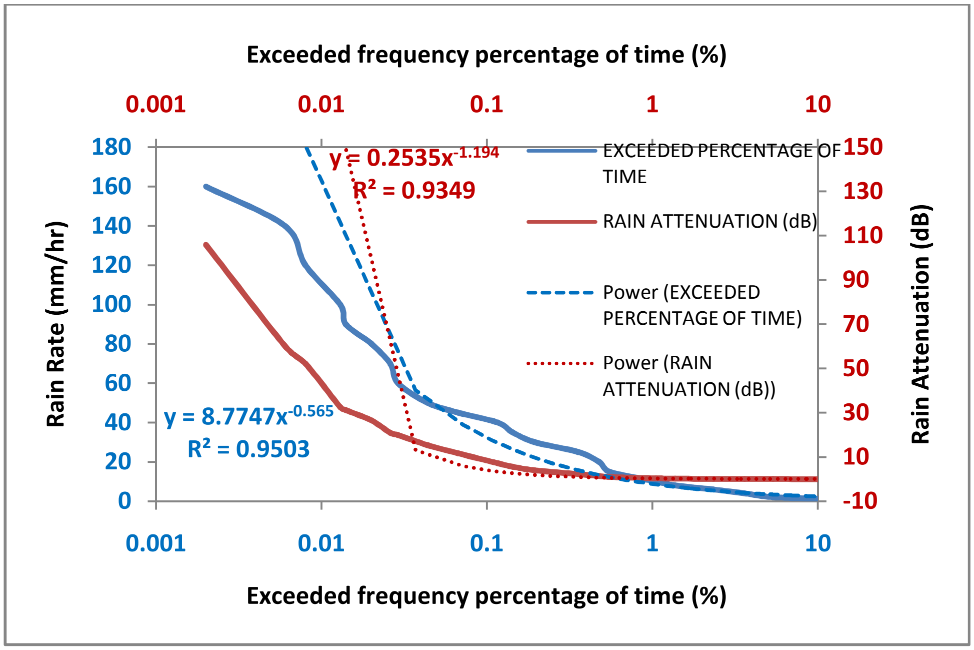

Figure 2: Relationship between Frequency percentage time and Rain Attenuation for July 2017

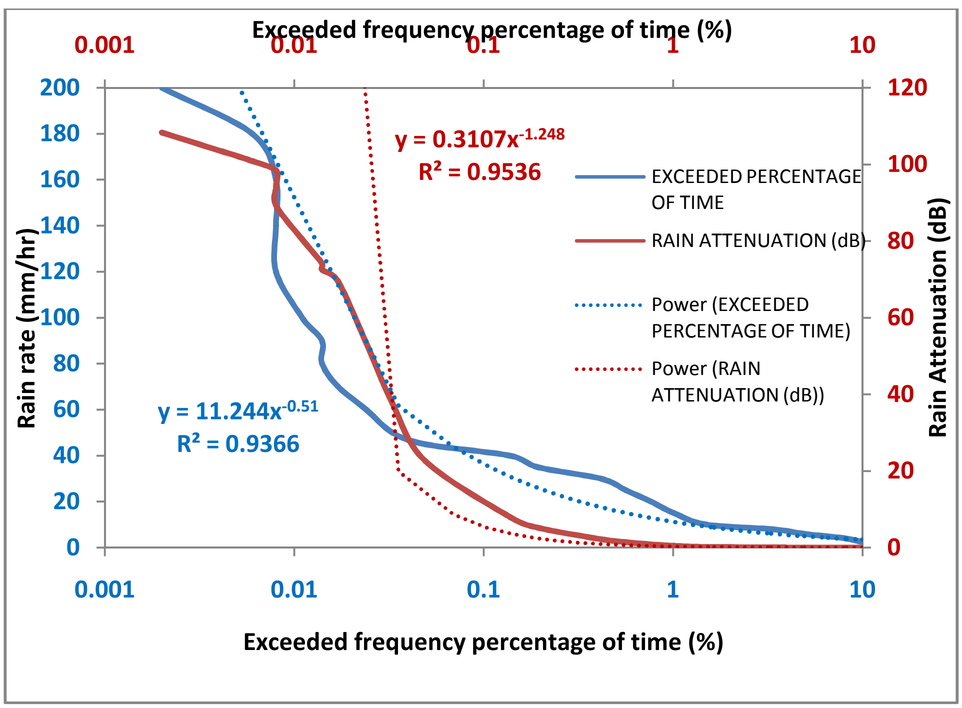

Figure 3: Relationship between frequency percentage time and Rain Attenuation for August 2017

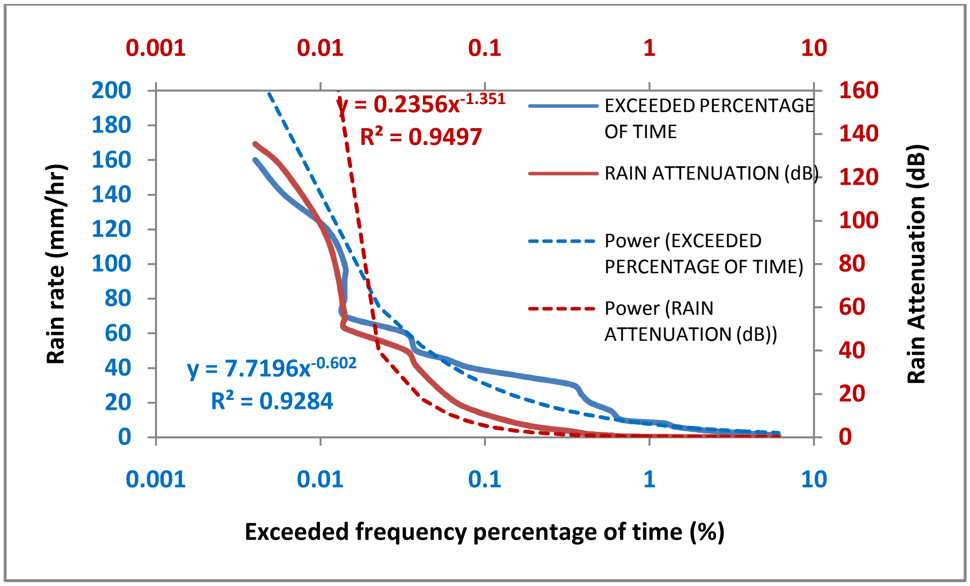

Figure 4: Relationship between frequency percentage time and Rain Attenuation for October 2017

4.0 DISCUSSION

Table 1 presents the Computation of rain rate, rain rate frequency, cumulative frequency, exceeded Frequency Percentage of Time and Rain attenuation for the month of July 2017 which shows that rain attenuated signals is more severe from rain rate of 90mm/hr at 0.014% to 160mm/hr at 0.002% with attenuation of 31.215dB and 105.951dB respectively. Table 2 presents the Computation of rain rate, rain rate frequency, cumulative frequency, exceeded Frequency Percentage of Time and Rain attenuation for the month of August 2017 which shows that rain attenuated signals become more severe from rain rate of 70mm/hr at 0.017% to 200mm/hr a t0.002% with attenuation of 69.509dB and 108.324dB respectively. Table 3 presents the Computation of rain rate, rain rate frequency, cumulative frequency, exceeded Frequency Percentage of Time and Rain attenuation for the month of October 2017 which shows that rain attenuated signals become more severe from rain rate of 70mm/hr at 0.014% to 160mm/hr at 0.004 with attenuation of 50.301dB and 135.336dB respectively.

Figure 2 presents the relationship between rain rate, Exceeded frequency percentage time and Rain Attenuation for the month of July 2017. Figure 3 presents the relationship between rain rate, Exceeded frequency percentage time and Rain Attenuation for the month of August 2017. Figure 4 presents the relationship between rain rate, Exceeded frequency percentage time and Rain Attenuation for the month of October 2017. These results shows that propagation losses on terrestrial radio links due to rain become more severe as the rain rate increase (above 70mm/hr) as the exceeded frequency percentage of time reduces from 0.01% to 0.001%.

5.0 CONCLUSION

This study has evaluated the propagation losses due to rain attenuated signal on terrestrial radio links. The results obtained revealed that rain attenuated signals on terrestrial radio links is more severe at higher rainfall rate (above 60mm/hr) and lower exceeded frequency percentage of time (0.014% to 0.002%). This result is in agreement with the International Telecommunication Union Recommendation (ITU-R, 2008) which stated that propagation losses due to rain can best be estimated at 0.01% and 0.001% exceeded percentage of time.

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AUTHORS’ CONTRIBUTIONS

Author A (IOJ) designed the study, wrote the first draft of the manuscript, set up the experiment, compelled the results and discussed them. Author B (ZJT) managed the measurement and analyses of the study. Auhor C (OEP) managed the literature searches. All authors read and approved the final manuscript.