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Effects of Rainfall Attenuation on Frequencies 1 and 3 GHZ in Nigeria

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Abstract

Mobile communications are part of our everyday life. The non-ideal environment which is filled with many attenuation factors affects the electromagnetic waves, which radio communication depends. This study considers the spectral range of 1 and 3GHz. At these frequencies, interesting phenomena due to rain are supposed to happen. The study of this frequency spectrum has been undertaken in an attempt to evaluate the frequency dependence of rain effects on electromagnetic waves. The study of rain effects on communication presented in this study relied solely on rainfall data collected from Nigeria Metrological Agency (NiMet) station in Lagos, Nigeria. The months for January to December for 1981-2011 were summed together and the averages were determined. The average is then used to calculate the rain rate and rainfall attenuation using the extracted results for all the locations (Bauchi, Ikeja, Jos, Kebbi, Maiduguri and Warri). The results show that Warri has the highest rainfall rate followed by Lagos. Kebbi and Maiduguri has the least while Jos and Bauchi demonstrated moderate rainfall rates. This also deduced that attenuation has less impact on lower frequencies but increase with higher frequencies. The study reveals that at higher frequencies, the rainfall attenuation is observed to be greater.

Key Words

Rain attenuation effects, rain rate analysis, Frequency range.

Academic Discipline

Physics, Electronics, Communication,

Subject Classification

Physics, Electrical and Electronics, Computer Engineering

Method

Data research

Introduction

Mobile communications are part of our everyday life, such as internet, satellite communications systems etc and such systems require a signal of higher performance. Systems can be degraded, particularly, in communication, due to absorption that causes attenuation in electromagnetic waves which equally limits the coverage of the system (Elfadil, 2005).

The electromagnetic spectrum, especially, 10 GHz embedded with throve of potentials such as large bandwidth capability, highly directive beams obtained with relatively small antennas, low transmitter power requirement, and better penetration of media with high ion density; some of these properties make those frequencies ideal for space communication systems. However, at certain frequencies above 5GHz, the absorption due to water vapour, oxygen and other gases do causes effect significantly on communication systems (Charles, 2001).

The actual atmosphere (as opposed to free space) affects the amplitude, phase, and polarization of electromagnetic waves at short wavelengths. Among the physical phenomena that cause these effects are dispersive molecular absorption (the two main absorbers being water vapor and oxygen), refractive effects that cause amplitude and phase scintillations (rapid fading), thermal emission that increases the background noise level and scattering and absorption by hydrometeors (Charles, 2001).

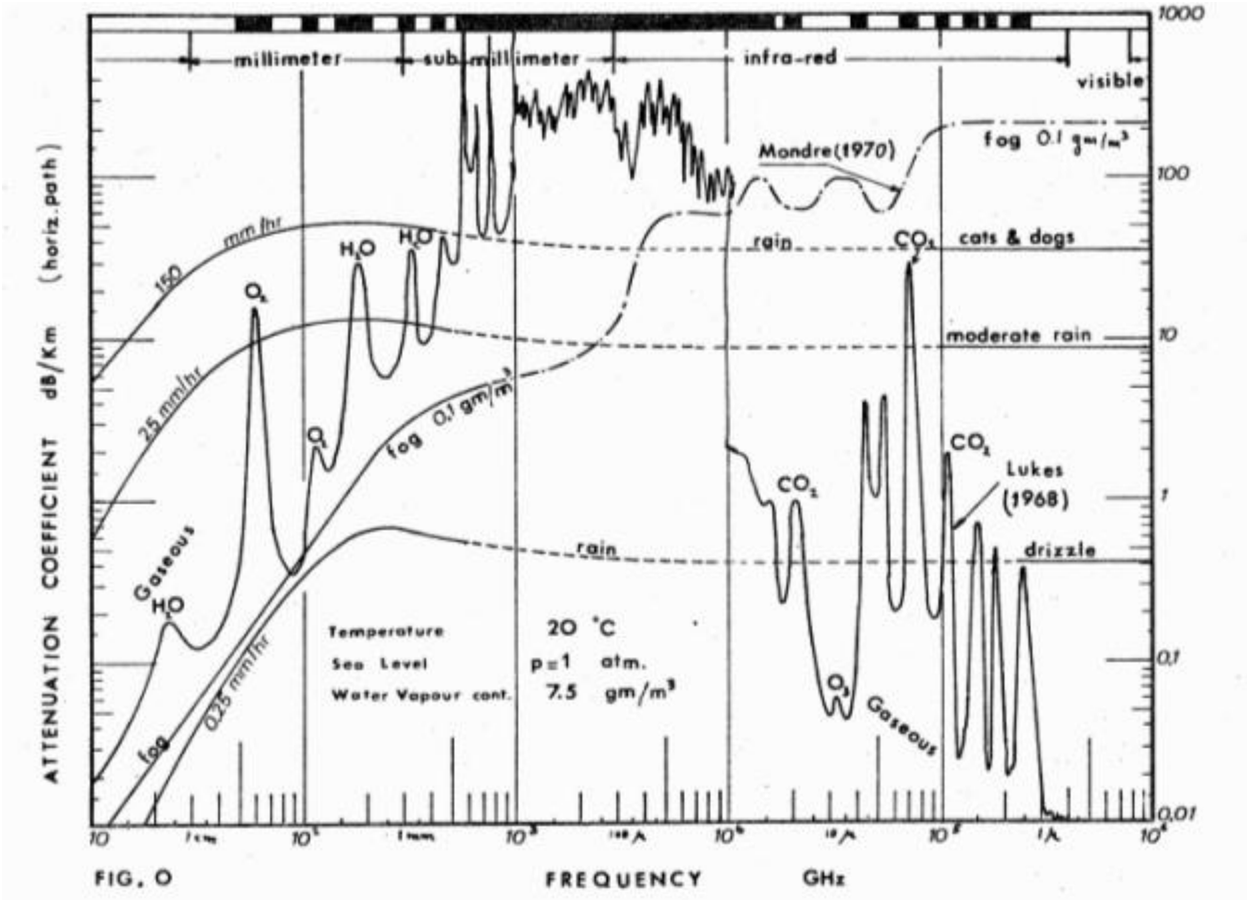


Figure 1: Attenuation coefficient versus Frequency.

Rain causes the most crucial effect in communication degradations and outage in any systems operating at frequencies above 5 GHz, except for certain applications, such as satellite communications. Water which freezes at 0^0c are mostly in the form of water vapour in the air, and when the air temperature falls below 0^0c the hydrometeors are formed as ice. Hence, the ice melts and falls as rain which causes effect in communication. (Mike Willis, 2007).

The actual atmosphere (as opposed to free to free space) affects the amplitude, phase, and polarization of electromagnetic waves at short wavelengths. Among the physical phenomenon that cause these effects are dispersive molecular absorption (two main absorbers being water vapour and oxygen), refractive effects that cause amplitude and phase scintillations (rapid fading), thermal emission that increases the background noise level and scattering and absorption by hydrometeors (Charles, 2001). These phenomenon (scattering and absorption) causes rainfall attenuations in different regions of the spectrums. This study considers the spectral range of 1 and 3GHz. At these frequencies, interesting phenomena due to rain are supposed to happen. The study of this frequency spectrum has been undertaken in an attempt to evaluate the frequency dependence of rain effects on electromagnetic waves.

Nigeria is located in the tropics, latitude $10^0\,00$N and longitude $8^0\,00$E, unlike the temperate environments such as Europe and North America. Apart from the orographic rainfall, rain in most parts of Nigeria is convectional in making. The heating of the land in the mornings and afternoons causes convectional currents to set in motion. The rising of the warm air triggers off the formation of cumulonimbus clouds (hot tower cloud) or the thunderstorm cloud in the afternoons and evenings, and torrential rainfall follows (schools-wikipedia.org, 2015). Precipitation is heavy, between 1824mm to 4000mm along the coast. The inland to hill and plateau region has the annual rainfall exceeds 2,500 mm as compared with the far north having annual rainfall below 1,000 mm in almost everywhere and in some places it is as low as 600 mm (bbc.co.uk, 2012, Crane, 1985).

Stratiform and Convective Rain

Two common rain types are convective rain and stratiform rain. At several kilometres, the convective flow which occurs in horizontal cell usually results in vertical atmospheric motion that could cause vertical transport and mixing of atmospheric elements. The cell may be isolated or embedded in a thunderstorm region associated with a passing weather front. Because of the motion of the front and the sliding motion of the cell along the front, the high rain rate usually only lasts for several minutes. These rains are the most common sources of high rain rate events (Nazar et al, 2005).

Stratiform rain typically shows a stratified horizontal extent of hundreds of kilometers, durations exceeding one hour, and low rain rates of less than 25 mm/hr. For communication applications, stratiform rain occurs for sufficiently long periods of time that a link margin may be required to exceed the resulting attenuation.

Raindrop size and shape

In the millimeter-wave range of the radio spectrum both the shape and the size of the raindrop are important. In addition, for a particular raindrop, the drop shape will depend on its size and the rate at which it is falling. In order to model the effects of rain attenuation and scattering of radio-waves, rainfall is usually characterized by drop size distribution, N (D), which is defined as the number of raindrops falling per cubic meter, with drop diameters, D, in the range D to D+ dD. The drop-size distribution is a function of the rain rate, R, which is usually measured mm/hr. Other parameters include the fall velocity of the drops and, the time of the year. Model predictions of attenuation due to rain had been standardized in ITU-R P.838, 2005.

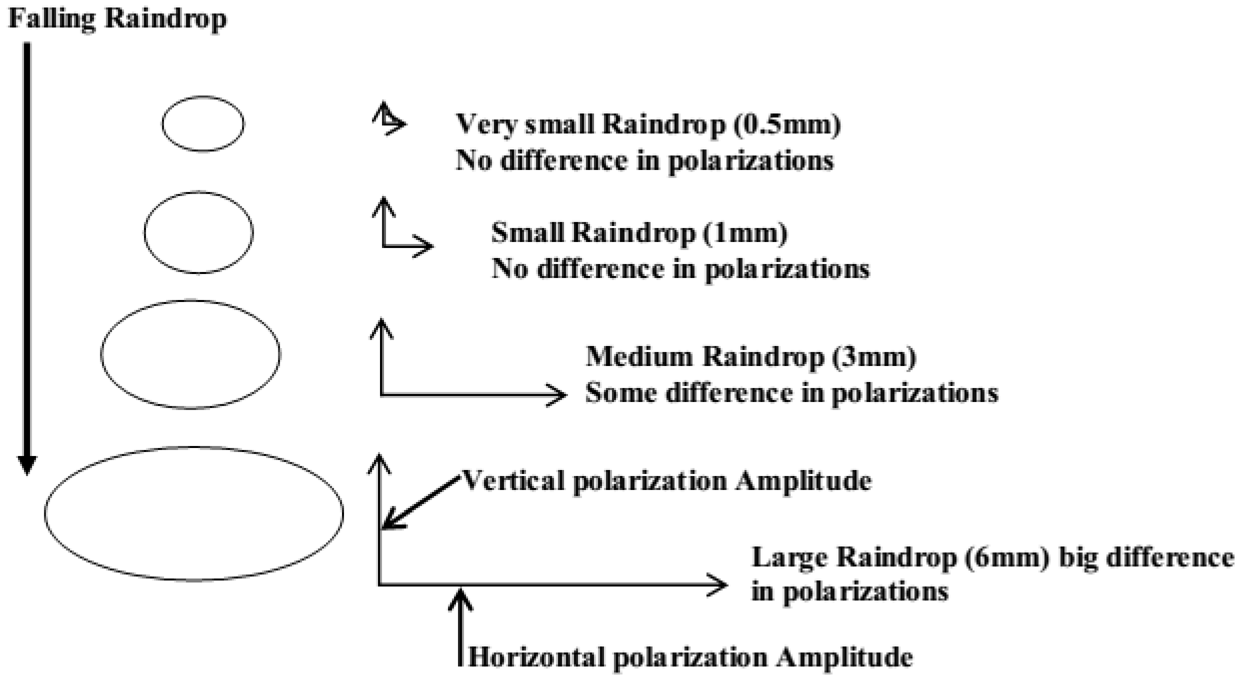


Figure 2: Raindrop size and shape

Radio wave propagation

Radio communication uses electromagnetic waves (EM) propagation through earth's atmosphere or space to carry information over long distances without the use of wire cable.

Signal transmission in a radio system is based on converting the electrical signals generated by the transmitter into electromagnetic waves, propagation of waves in space and conversion back into electrical signals at the receiver side of the system (Jinan, 2010).

The propagation channel, together with the antennas, constitutes the radio channel as shown in the Figure. The communication channel is described in terms of the bandwidth which determining the maximum information rate of the channel. The channel can introduce various kinds of distortion and delay into the signal.

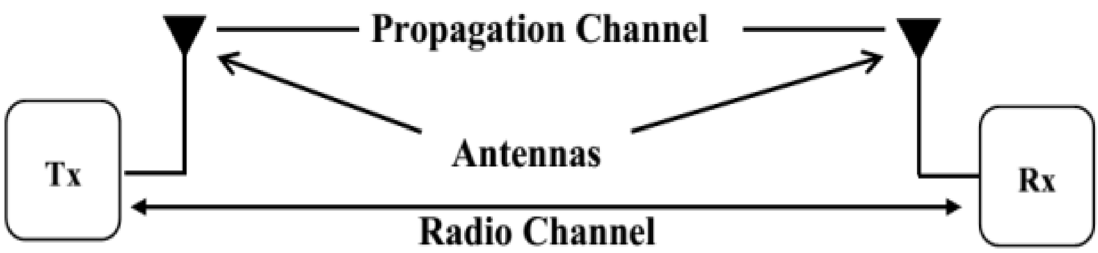


Figure 3: Radio and Propagation Channels (Jinan, 2010).

Rain Attenuation Prediction Models

Methods for prediction of rain attenuation on radio wave path have been grouped into two categories: physical method and empirical method (Mukeshi, 2014). There are others various attenuation models like the Global (Crane)

Model, Initial Two-Component Model, and Revised Two Component Model are another model that can be used to predict rainfall attenuation (Kamal, 2010).

Physical Methods

Analytical models produce physical models that are involved in attenuation processes when some input parameters are required, these also give a physical process that ere involved in radio wave propagation (Ojo *et al*, 2008).

Empirical Method

The data collected from database stations taken from different climatic zones were considered during the period of the research and referred to as empirical models.

Calculation of Excess Path Attenuation

The attenuation due to rain can be calculated using the relation:

$$\gamma = aR^b \quad \text{dB/km} \qquad (1)$$

Where **γ** is Rainfall attenuation (dB/Km), **a** is the multiplier coefficient and exponent, **b** is the power-law equation and **R** is the rain rate (mm/hr) a and b are constants provided in table 1 below:

Table 1: Interpolated Regression coefficients Table for 1-6 GHz.

f (GHz)	a	b
1	0.0000387	0.912
2	0.000154	0.963
3	0.0003576	1.055
4	0.00065	1.121
5	0.001121	1.224
6	0.00175	1.308

Source: Table 10A.2 from (Adel et al, 1985)

Simplified rain scatter model

A simple model for bistatic rain scatter is shown below; it makes many assumptions to avoid complex mathematical derivations which require a solution of equation (2).

$$P_r = P_t \frac{\lambda^2}{(4\pi)^3} \iiint_{all\ space} \frac{G_t G_r \eta A}{r_t^2 r_r^2} dV \qquad (2)$$

$$V = \pi d_{r^2}/4\ h_r \qquad (3)$$

Remembering h_r is around 3km and$d_r \sim 3.3R^{-0.08}$, for Heavy rain, R = 50mm/hr or more, d_r = 2.4km, V = 23 km^3

Bistatic radar equation was applied to calculate the scattered power. The power received by scatter from rain located at a distance d_r from the receiver is related to the power transmitted P_t at a distance d_t from the rain by:

$$P_r^{scat} = P_t \frac{G_t G_r \lambda^2}{(4\pi)^3 d_t^2 d_r^2} \sigma \qquad (4)$$

σ is the scattering function. A useful model for σ is:

$$10 \log \sigma = -22 + 40 \log f + 16 \log r + 10 \log V + 10 \log S \qquad (5)$$

MATERIALS AND METHOD

The experimental systems involved in the study and the procedures of data processing employed to isolate attenuation-induced fluctuations of received signal level from other causes of variations in the raw data.

The nondeterministic nature of propagation phenomena such as rain attenuation necessitates extensive measurements to build up a statistically significant database in order to reliably predict and quantify the effects of these propagation factors to aid system design. The study of rain effects on communication presented in this study relied solely on rainfall data collected from Nigeria Metrological Agency (NiMet) station in Lagos, Nigeria.

The months for January to December for 1981-2011 were added together (Table 2) and the average were determined (Table 3).The average is then used to calculate the rain rate and rainfall attenuation. The extracted results for all the locations (Bauchi, Ikeja, Jos, Kebbi, Maiduguri and Warri) were plotted on various graphs (Figures 5 - 10)

Table 2: Total Rainfall for all the six selected regions between 1981 – 2011 (mm/hr)

YEAR	BAUCHI	IKEJA, LAGOS	JOS, PLATEAU	MAIDUGURI	WARRI,DELTA	YELWA,KEBBI
1981	1250.8	1470.8	3553.4	461.4	2349.9	556.9
1982	897	1034.4	1330.4	354	3056.9	569
1983	773.3	894.7	1175.1	263.5	2521.6	620.7
1984	893.7	1375.5	1155.1	348.1	2697.5	467
1985	725.6	1228.9	1161.7	414.1	2976.6	434.8
1986	946.1	1040.8	1206.5	509.5	2915.8	475.8
1987	744.6	1675.8	1289.1	366.3	2775.6	324.5
1988	920.7	1939.4	1237.7	595.8	2708.8	697.3
1989	909.4	1368.7	1212	610.3	2571.5	522.8
1990	879.6	1611.7	1230.8	429	3098.8	654.2
1991	949.6	1671.7	1308.5	486.1	2920.7	759.4
1992	1230.4	1183.9	1173.3	584.6	3060.3	549
1993	1141.9	3668.6	1124.5	490.7	3010.6	642.2
1994	1067.3	1195.6	1165.9	426.6	2807	762.1
1995	961.4	1629.8	814.7	686.1	3337.8	509.6
1996	1140.6	1575.4	1382	630.5	2705.7	729.9
1997	896.7	2019.9	1329.1	549.7	3227.3	645.5
1998	1122.6	1039.9	1261.3	692.2	2448.5	845.9
1999	1400.6	1229.7	1148.2	843.6	3396.6	711.6
2000	1058.9	1251.1	1161.2	677.4	2722.2	732.6
2001	1307.4	1392.1	1089.3	727.7	2390.2	731.6
2002	819.1	1794.6	1582.7	444.1	3312.2	768.7
2003	989.5	1677.6	1315.2	653.3	2329.4	790.2
2004	865.9	1690.7	1212.2	603.8	3064	649.5
2005	1034.5	1484.9	1203.5	917.3	2368.6	635.1
2006	1017.9	3681.2	1248.4	553.7	3031.1	745.5
2007	1147.5	1649.1	1359.2	730.7	2534.5	644.1
2008	1133.3	1679.3	1286	565.7	3112.8	494.3
2009	1451.3	1319.6	1187.7	582.6	2775.1	603
2010	1547	1409.5	1387.2	393	2591.2	1140.9
2011	1556.8	1761.6	1182.4	543.3	2924.3	557.8

Table 3: The average rainfall for the six locations for the period of 1981-2011 (mm/hr)

YEAR	BAUCHI	IKEJA, LAGOS	JOS, PLATEAU	MAIDUGURI(BORNO)	WARRI,DELTA	YELWA,KEBBI
1981	104.23	122.56	106.03	38.45	195.83	46.41
1982	74.75	86.2	110.87	29.5	254.74	47.42
1983	64.44	74.56	97.93	21.96	210.13	51.73
1984	74.48	114.625	96.26	29.01	224.79	38.92
1985	60.47	102.41	96.81	34.51	248.07	36.23
1986	78.84	86.73	100.54	42.46	242.98	39.65
1987	62.05	19.65	107.43	30.53	231.3	27.04
1988	76.73	161.62	103.14	49.65	225.73	58.11
1989	75.78	114.06	0.00101	50.86	214.29	43.57
1990	73.3	134.31	102.57	35.75	258.23	54.52
1991	79.13	139.31	109.04	40.51	243.39	63.28
1992	102.53	98.66	97.78	48.72	255.03	45.75
1993	95.16	139.63	93.71	40.89	250.88	53.52
1994	88.94	99.63	97.16	35.55	233.92	63.51
1995	80.12	135.82	67.89	57.18	278.15	42.47
1996	95.05	131.28	115.17	52.54	255.48	60.83
1997	74.73	168.33	110.76	45.81	268.94	53.79
1998	93.55	86.66	105.11	57.68	204.04	70.49
1999	116.72	102.48	95.68	70.3	283.05	59.3
2000	88.24	104.26	96.77	56.45	226.85	61.05
2001	108.95	116.01	90.78	60.64	199.18	60.97
2002	68.26	149.55	131.89	37.01	276.02	64.06
2003	82.46	139.8	109.6	54.44	194.12	65.85
2004	72.16	140.89	101.02	50.32	255.33	54.13
2005	86.21	123.74	100.29	76.44	197.38	52.93
2006	84.83	139.6	104.03	46.14	252.59	62.13
2007	95.63	149.92	113.27	60.89	211.21	53.68
2008	94.44	139.94	107.17	47.14	259.4	41.19
2009	120.94	109.97	98.98	48.55	231.26	50.25
2010	128.92	117.46	115.6	32.75	215.1	95.08
2011	129.73	146.8	98.53	45.28	243.69	46.48

RESULTS AND ANALYSIS

Empirical model is used to solve the rain attenuation using $\gamma = aR^b$ (dB/km) with constants in Table 1. The reason for the choice of empirical model is because it is based on the data collected from database stations taken from different climatic zones during the period of the research for simplicity of the mathematical expressions. The excel calculation solver is used to solve all the data used in this study due to large data involved.

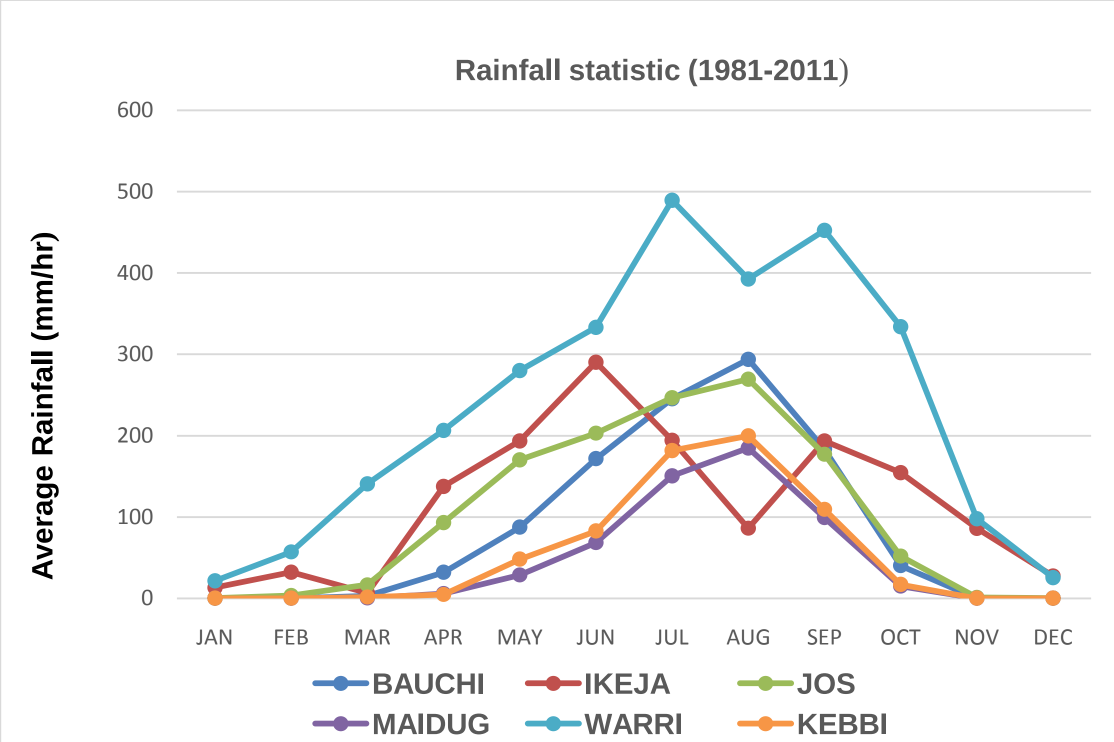
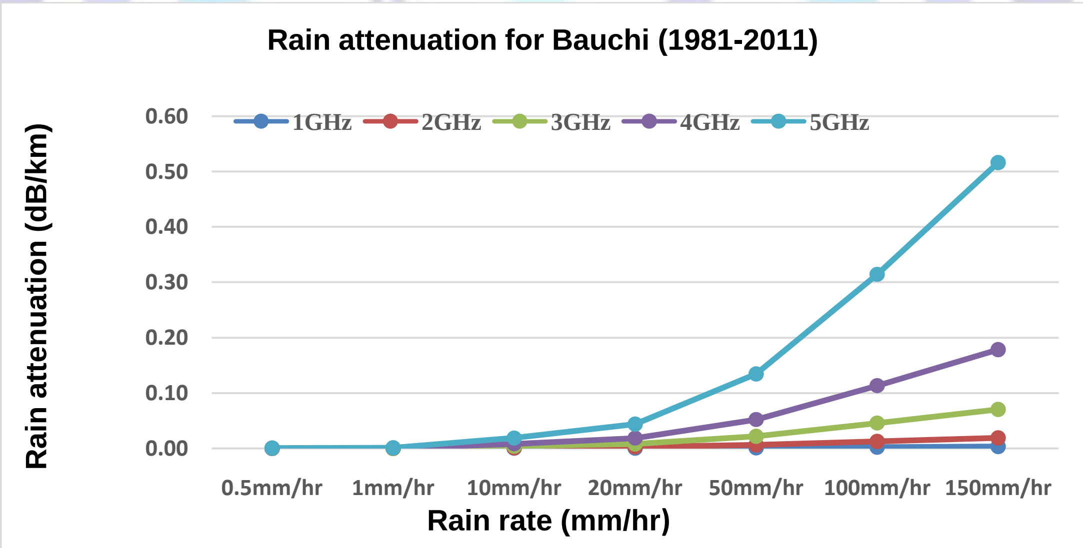


Figure 4: Curves shown the Rain rate for 1981-2011

The figure above shows the rainfall statistics for the period of 1981-2011. It clearly shows that Warri has the highest rainfall rate (having average rainfall ≥ 400 mm/hr in July) followed by Ikeja and Bauchi with ≤ 300 mm/hr average rain rate between June - August. The two states fall in mangrove costal region and always have two season of rainfall per year. The average rainfall for Jos and Bauchi are closely related in rainfall rate. They are located in the middle-belt unlike Kebbi and Maiduguri which are located in the far north with less average rainfall with ≤ 200 mm/hr.



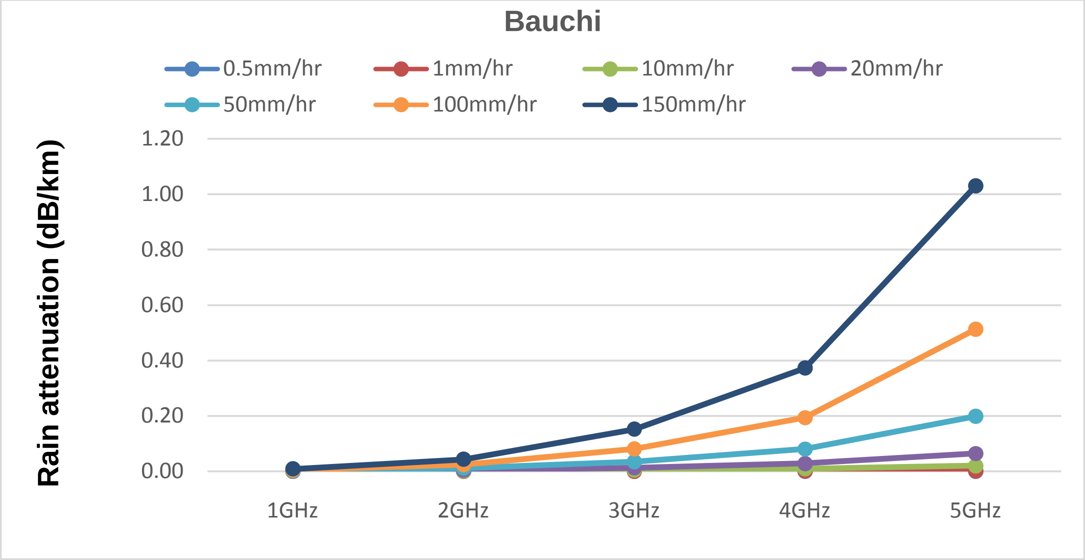
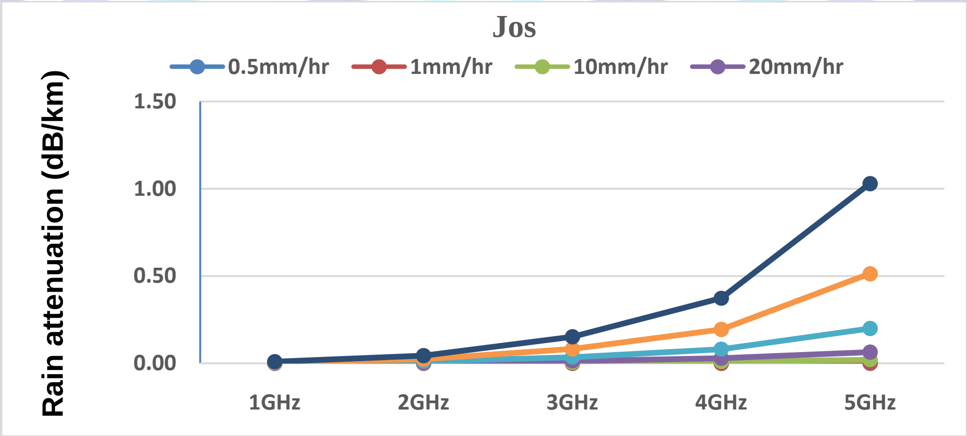
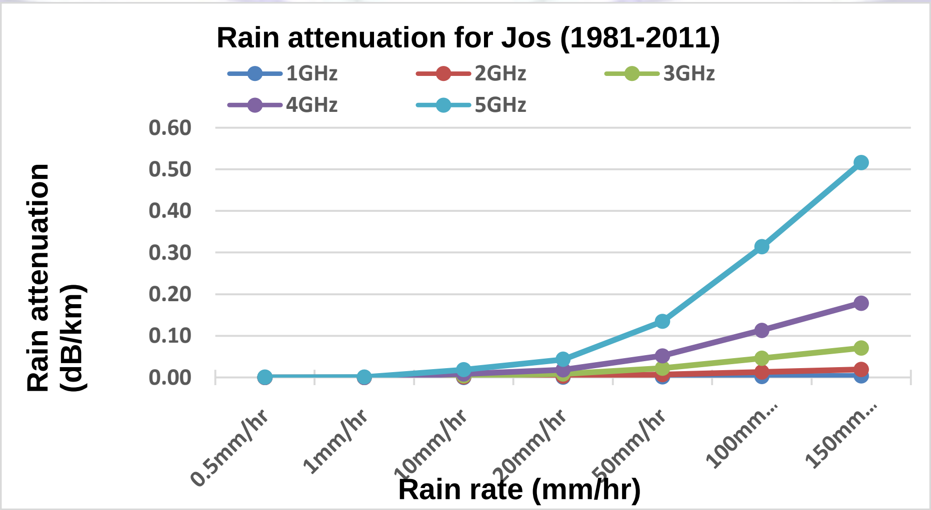


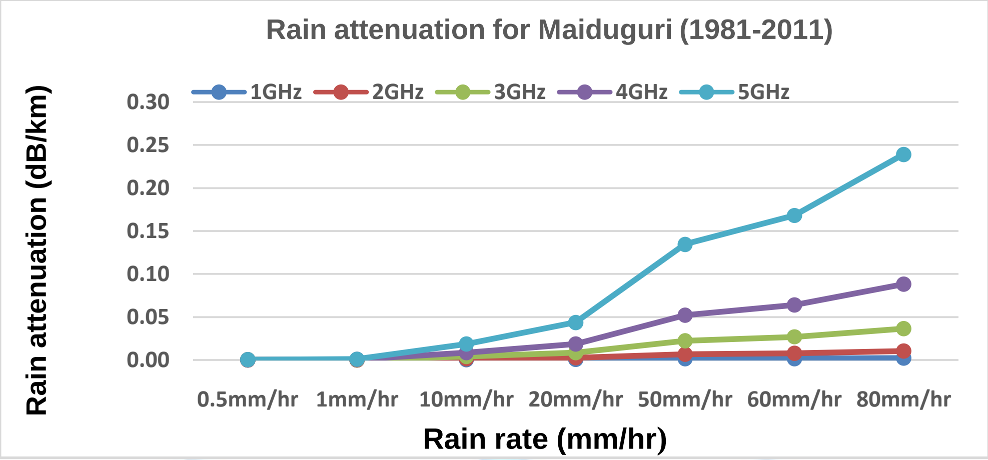
Figure 5: Rain attenuation for Bauchi

Figure 5 shows rainfall attenuation and rain rate for Bauchi; which has its highest rain attenuation of 0.50 db/km at 150mm/hr rain rate and ≤ 0.20 db/km at 150mm/hr rain rate. It is however, clear from the results that only the frequency 5GHz that operates at the highest rain attenuation.





Meanwhile, Jos which lies within the same coast with Bauchi has its highest rain attenuation of ≥ 0.50db/km at 150mm/hr and least of ≈ 0.10 db/km. The results show that only 4 and 5 GHz attains between 0.1 – 1 db/km rain attenuation.



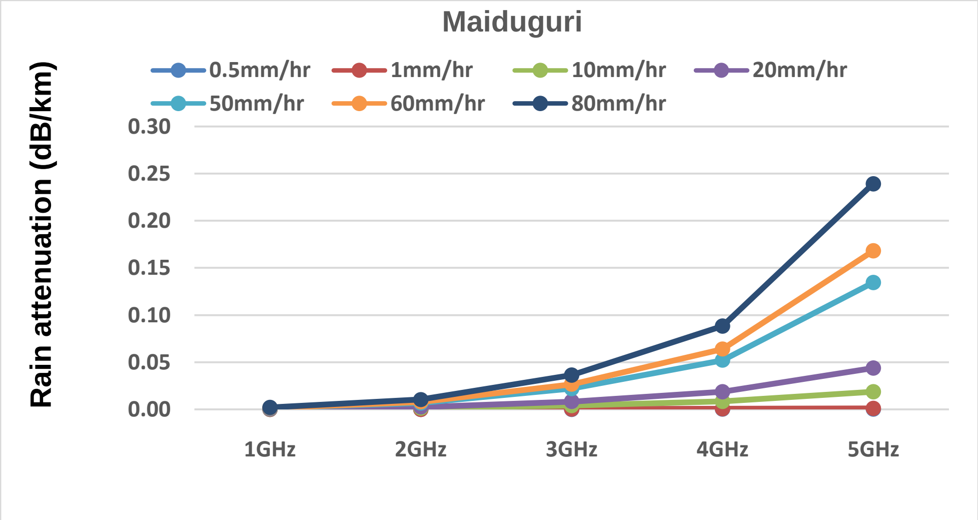
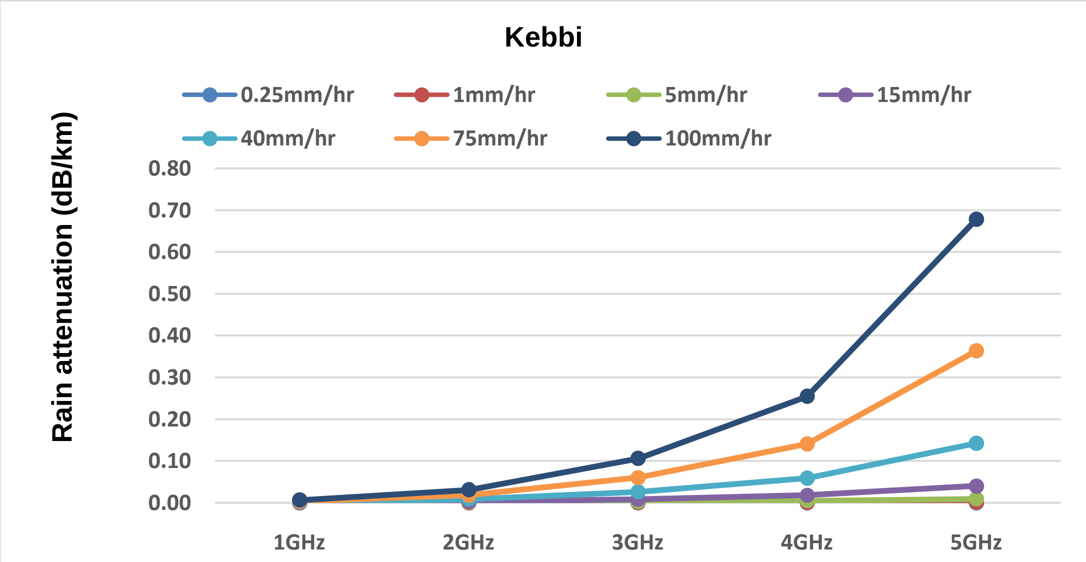


Figure 7 indicated that the rain attenuation in Maiduguri is ranging from 0.01 – 0.24 db/km at 80mm/hr. Maiduguri has the best rainfall attenuation due to low rainfall in the region.



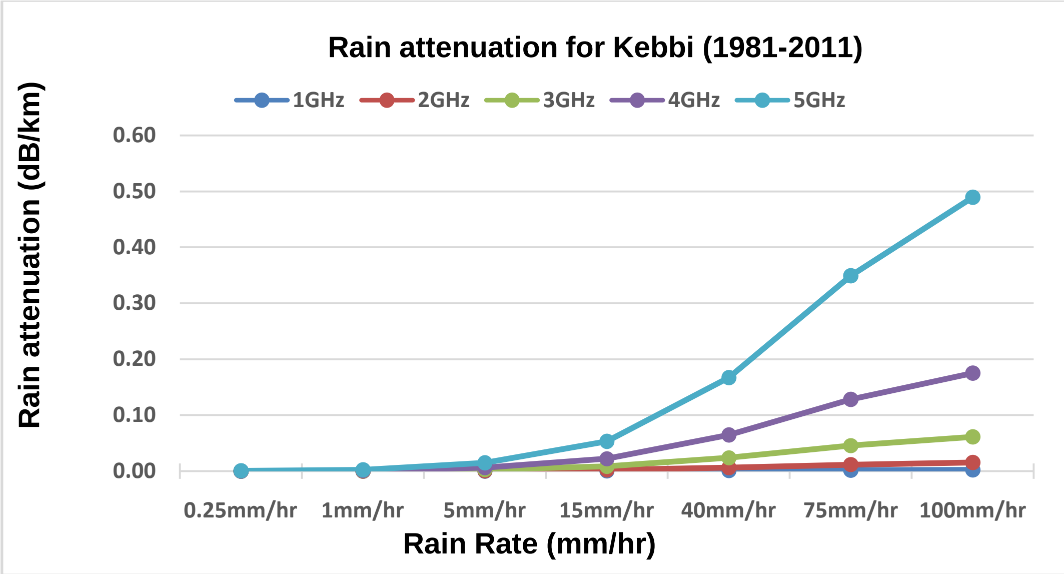


Figure 8: Rain attenuation for Kebbi

From the figure above, it shows that rain attenuation in Kebbi for the period considered indicated that the highest rain attenuation is ≤ 0.50db/km at 100mm/hr and least at approximately 0.05db/km.

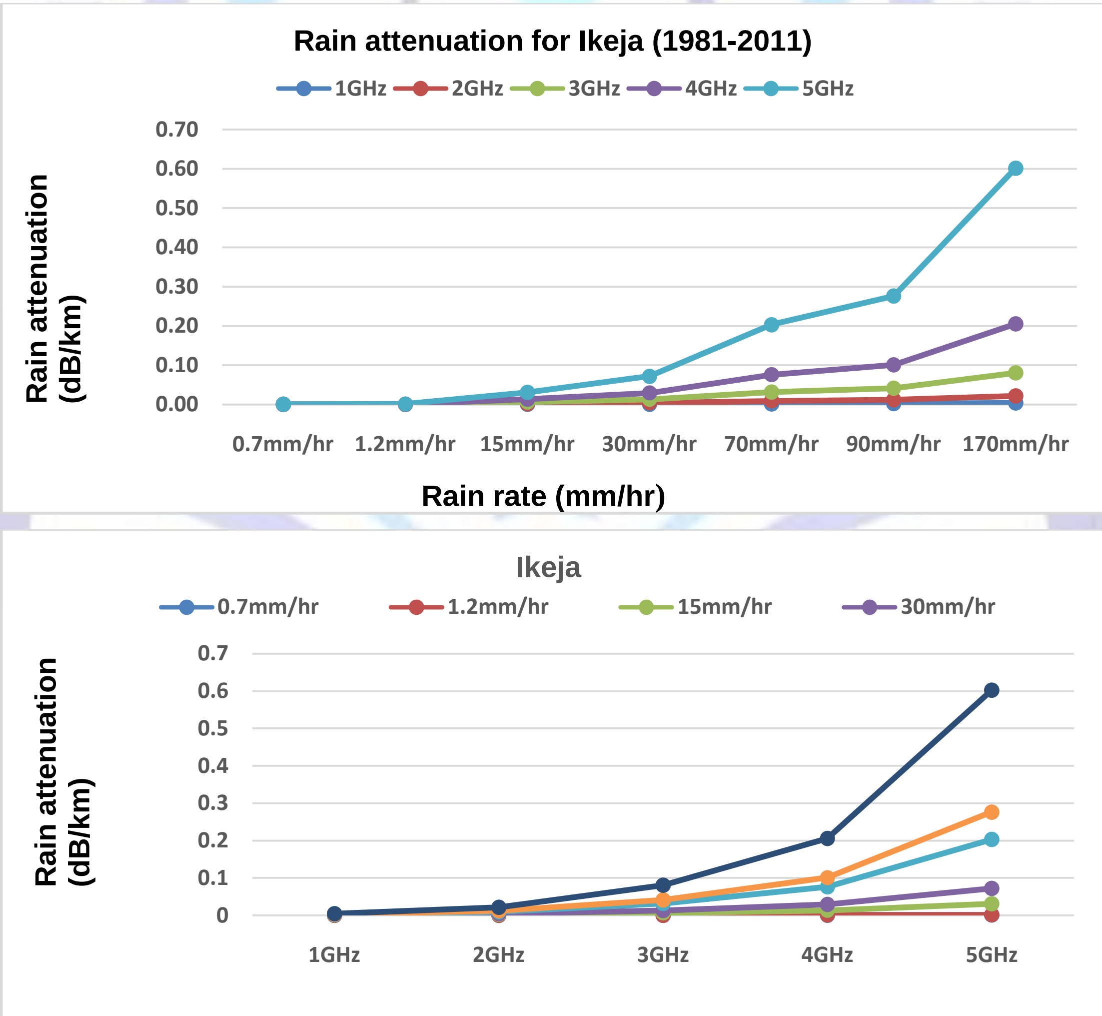
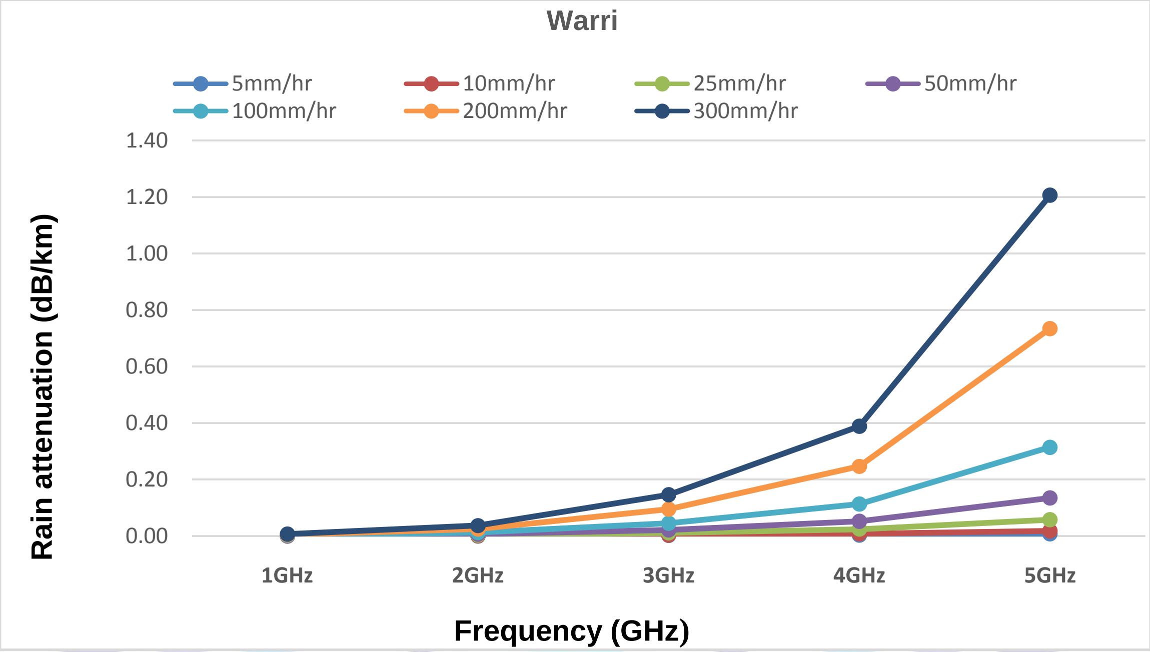


Figure 9: Rain attenuation for Ikeja

Figure 9 above shows the rain attenuation of Ikeja, having rain attenuation ranging from 0.01 - ≥ 0.60db/km at 170mm/hr. The rain attenuation here is a little higher than the other states discussed above.



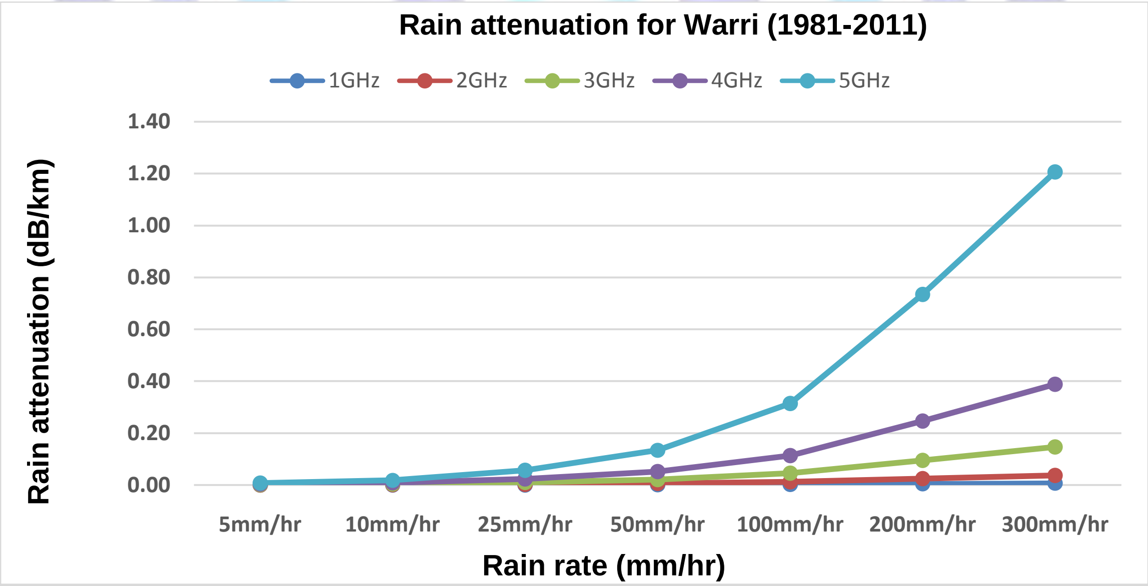


Figure 10: Rain attenuation for Warri

Figure 10 presents the rain attenuation of 0.02 - ≥ 1.20db/km at 300mm/hr, which of course shows a high variation in rain attenuation from other states in the this study.

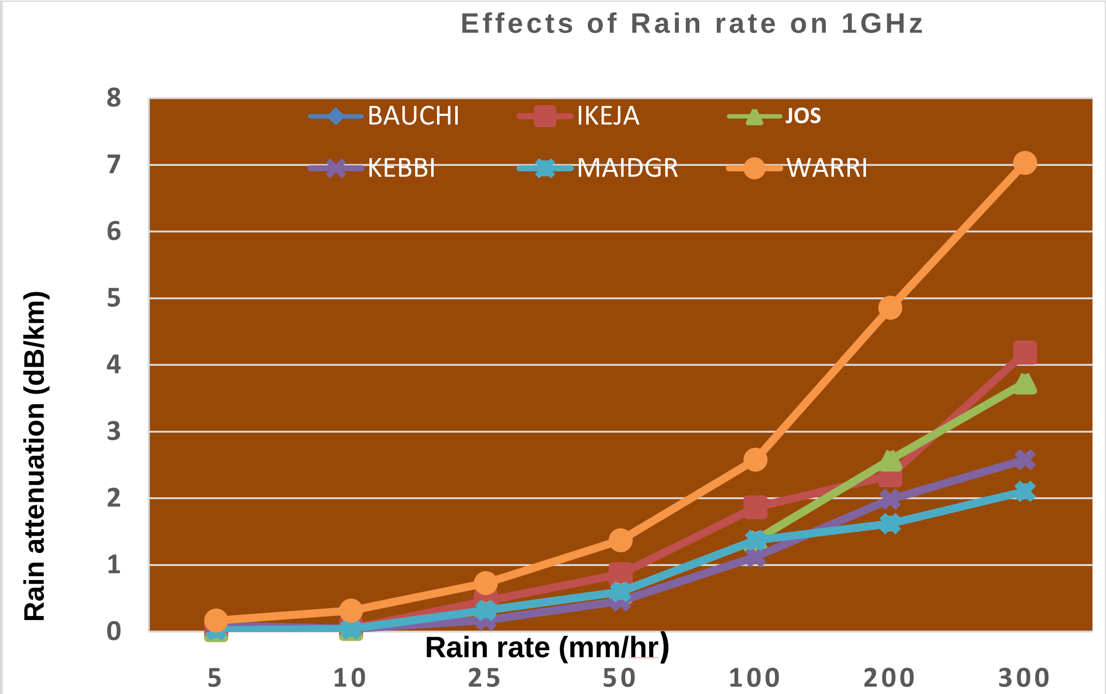


Figure 11: Effects of Rain rate on 1GHz

Figure 11 shows that attenuation has less impact on lower frequencies but increase with higher frequencies.

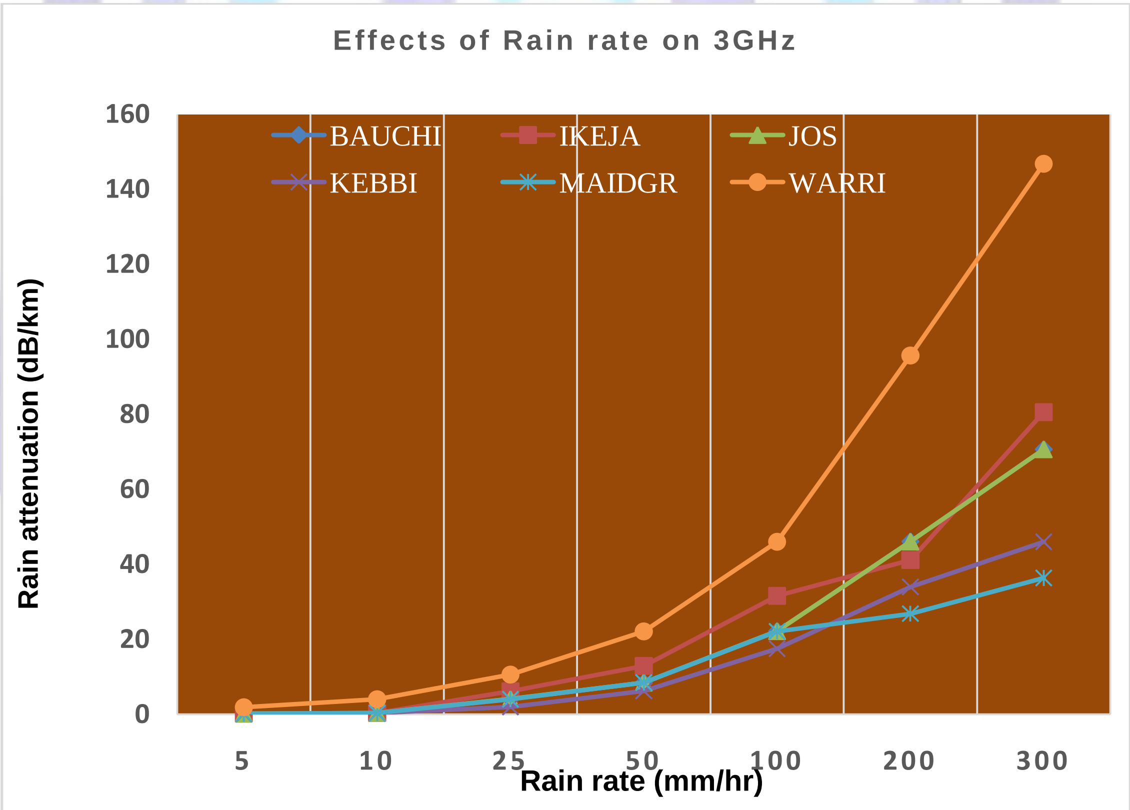


Figure 12: Effects of Rain rate on 3GHz

Similarly, figure 12 displayed the effect of rainfall attenuation on frequency 3GHz for all the six states, where Warri has rain attenuation of ≥ 140db/km at 300mm/hr rain rate and Maiduguri having rain attenuation of ≤ 40db/km at 300mm/hr; while the other states ranging from 40 -80db/km rain attenuation at 300mm/hr rain rate; Which shows that rain attenuation has less impact on lower frequencies but increase with higher frequencies.

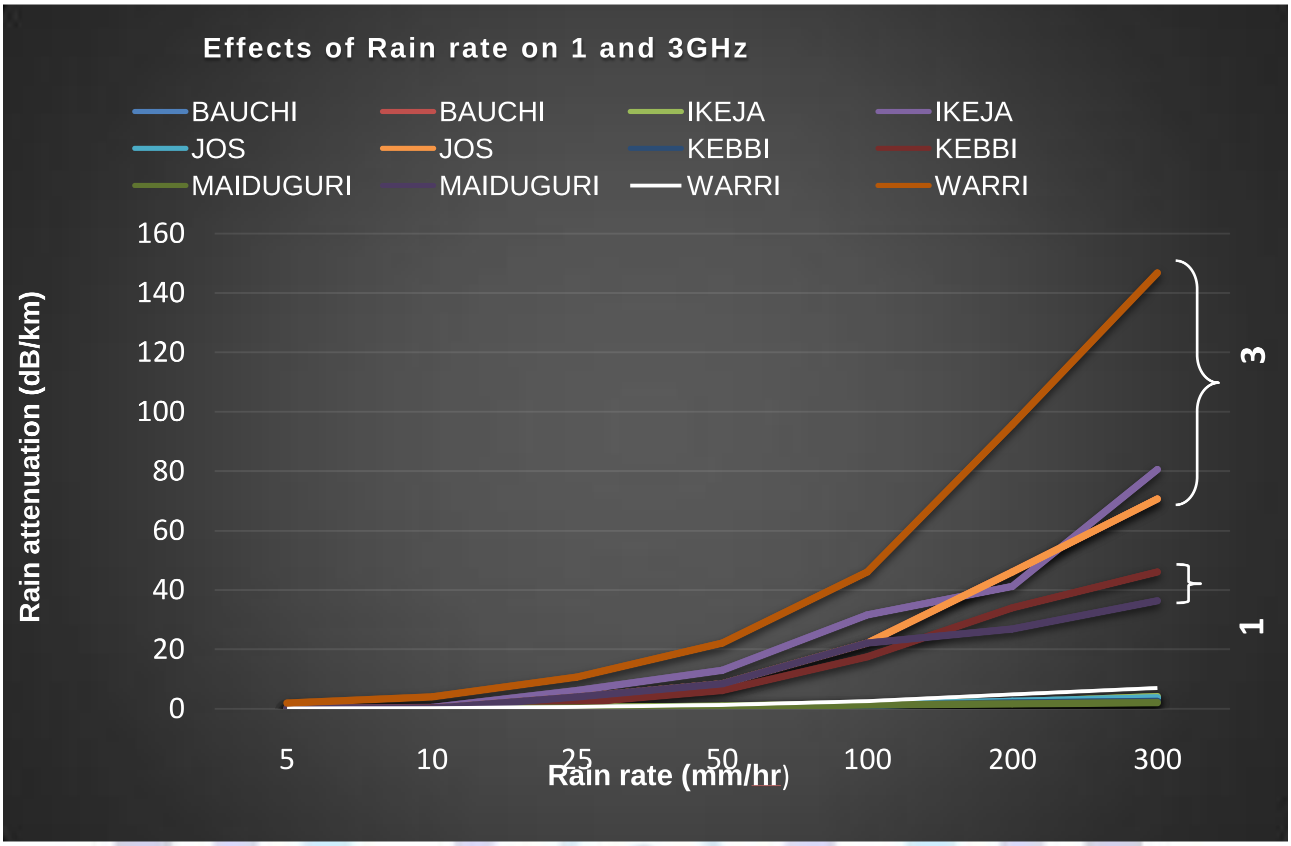


Figure 13: Effects of Rain rate on 1 and 3GHz

Attenuation is evaluated with respect to rainfall rate. It was also shown in figure 6-11 that the higher the rainfall rate, the higher the attenuation. Warri has the highest rain attenuation.

Conclusion

The study has shown that rain causes attenuation of certain frequencies is due to absorption and scattering. Rain attenuation in this research is modelled from data collected from Nigeria Metrological Agency, Lagos for different states. Rainfall attenuation that affects high quality mobile communication has been considered in this study. Planning wireless network for communication, demands the path loss and broadcast signal coverage for the location. The demand for increased data rates and greater bandwidths has required systems to use radio frequencies in the microwave bands. The study had shown that in today's wireless communications and satellite communications, it requires signals of higher output with higher gain, wider band width that cannot be easily attenuated.

Since EM waves are most effected by scattering and absorption phenomena, these factors must be put into consideration for improving mobile links in Bauchi, Ikeja, Jos, Kebbi, Maiduguri and Warri.

However, the effect of attenuation appears to be more pronounced with different rainfall rate; the results help find that rain rate and rain precipitation affect attenuation adversely. Attenuation is very high for higher rain rate.

Acknowledgement

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Author’s biography

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