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Empirical Rain-based Attenuation Quantification and Impact Analysis on 5G New Radio Networks at 3.5GHz Broadband Frequency

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Abstract: Today, rain remains one key and well-known natural phenomenon that offsets and attenuates the propagated radio, microwave, and millimeter-wave signals at different transmission frequencies and wavelengths over propagation paths. Specialised rain attenuation studies can be utilized to analyze their stochastic behavior on propagated radio signals and also come up with appropriate rain attenuation model for network application planning and optimisations. In this contribution, empirical rainfall depths data has been acquired, effectively categorized, and employed to examine the implicative intensity level trends over a ten years period, starting from 2011 to 2020. More importantly, the Recommendation ITU-R P.1511 power-based model combined with the acquired categorized rainfall depths data has been explored to prognostically estimate and quantity the amount of specific attenuation loss due over 3.5G transmission frequency. The results reveal that the level of attenuation attained versus 0.01% percentage of time depends on the type of rain intensity levels (heavy rain, very heavy rain, extremely heavy rain), which in turn is dependent upon rain depth or rate drop sizes. As a case in point, 0.001 percent of the time due to heavy rain, the amount of specific attenuation attained stood at 2dB, while for very heavy and extremely heavy rain, the specific attenuation levels amount to 2.3dB and 4dB respectively. These different amounts of specific attenuation simplify imply that the heavier the rain, the more scattering, and absorption the propagated electromagnetic signals undergo, thus leading to degraded and higher attenuation levels. The empirical based-rain attenuation quantification and impact analysis method explored in this paper will significantly provide radio network engineers with the best way to monitor and evaluate the radio attenuation effect over a propagation channel.

Index Terms: Rain depth, Heavy rain, very heavy rain, Extreme heavy rain, Rain Intensity, Specific attenuation level, New Radio Networks.

1. Introduction

The propagation of electromagnetic wave signals at lower and higher broadband frequency spectrum offers wide-ranging benefits which include but are not limited to the following: increased bandwidth, high data rate, improved spectrum efficiency, low latency, high transmission capacity, and low traffic delay, [1, 2]. However, the high attenuation and degradation of propagation of electromagnetic wave signals at different radio, microwave, millimeter wavelengths and transmission frequencies over different communication paths and broadband channels in space is a major concern to stakeholders, experts, and engineers in the telecommunication industry [3, 4].

One of such well-known natural phenomena that offsets and attenuates the propagated radio, microwave, and millimeter-wave signals at different transmission frequencies and wavelengths over propagation paths is the rain [5-8]. Rain upsets electromagnetic signals during propagation, as they spread through the troposphere region of the atmosphere owing to drastic effects on its amplitude scattering and absorption by the raindrops. The resultant effect of such phenomena is high cellular networks signal coverage outage and low network reliability at the user equipment terminals. In addition, raindrops alter the depolarization and amplitudes of transmitted signals, thus causing depolarization effects at the user receiver terminals. This electromagnetic signal offset is particularly more pronounced in tropical regions where very heavy and torrential rainfall intensities are experienced. Rain-induced signal fluctuations and attenuation analysis play the main role in the design and placement of terrestrial and geo-satellite radio links.

So, the need to regularly conduct a practicable based oriented study in order to constantly estimate its impact on propagating signals and make provision for them so as to ensure the quality at various transmission frequencies between the user receiver end and the transmitting stations cannot be oversized. Specialised rain attenuation studies can be utilized to analyze stochastic propagated signals behavior during rain and also come up with appropriate rain attenuation model for network application planning and optimisations.

2. Literature Review

As mentioned earlier, rain attenuation remained one key factor causing, high offsets, large degradation, and losses of propagated signals problems over different communication links on the terrestrial earth's surface. Rain attenuation varies from one location to another, depending on numerous factors like transmission frequency, seasonal variation, terrain type, temperature levels, air masses movement, and other factors [5, 7]. In order to successfully design cellular communication links at a specified frequency for enhanced service quality provisioning in any location, it is important to prognostically determine and estimate the attenuation levels caused by different rain depths /intensity and also make provision for their impact in correspondence with the regions or locations where the communication link is to be publically deployed. Our research work is motivated to undertake the above task. In practice, the parameters of rainfall depths, raindrops, rain intensities, and attenuation effects are practically investigated to enhance the replanning and post-planning of wireless broadband communication links.

Particularly, numerous works on rain rate (rain intensity) analysis and their attenuation impact on communication links have been reported in the literature, but mostly conducted at higher Millimeter-wave frequencies, ranging from 10–300 GHz, except one or two few ones that reported at lower frequencies, such as 7 GHz [8] and 5 GHz [9]. For instance, in [10-20], empirical-based analysis of rain rate and their attenuation levels are reported for different counties and environments. Specifically, clear research works on rainfall attenuation impacts on radio links have also been reported in some Africa Countries like Nigeria [21-23] and South Africa [24]-[26], but also at higher frequencies.

The paper's main objective is to perform an empirical based-rain attenuation quantification and impact analysis on 5G new radio networks at 3.5GHz broadband frequency in Nigeria. This has been achieved through the following contributions. Firstly, a ten-year of rainfall depths data have been acquired, categorized, and employed to examine their implicative intensity level trends over a period of the past ten years 3.5G transmission frequency. Secondly, the Recommendation ITU-R P. 1511-based model has explored to prognostically estimate and quantity the amount of specific attenuation loss due to the categorized rainfall depths over 3.5G transmission frequency, which has recently been proposed for 5G New Radio Broadband Networks deployment in Nigeria.

3. Materials and Methodology

The block diagram by which the research work is piloted is presented in Fig. 1. It begins by acquiring the rain depth data. This was followed by calculating and categorizing the rain intensity (i.e. rain rate) into three parts as revealed in Table 1. The seven steps implementation algorithm determining the specific attenuation due to Rain depth/intensity at 0.01% percentage of time using the Recommendation ITU-R P.1511 in MATLAB 2018 platform is also contained in this section.

A. Study Location

Kogi state, also widely known as the confluence state, is used as a case study in this work. The State is situated in the middle-belt (mid-central) region of Nigeria with latitude 7° 30´N and longitude 6° 42´E. It has an average population of about 3,595,789 and a 29,833km^2 area in terms of total land cover. The state is drainage constrained by Benue and Niger rivers and well as their tributaries. There exist two main seasons in the state, namely the dry season and rainy season, with respective 38^{0}C and 28^0 average temperatures. While the rainy period usually last between April and October yearly, but the dry season period, which is often very cold and dusty owing to northeasterly winds and rocky terrains, usually lasts between November and March, every year. Shown in Fig. 2 is a chart displaying yearly depths of rainfall in mm from 2010 to 2020.

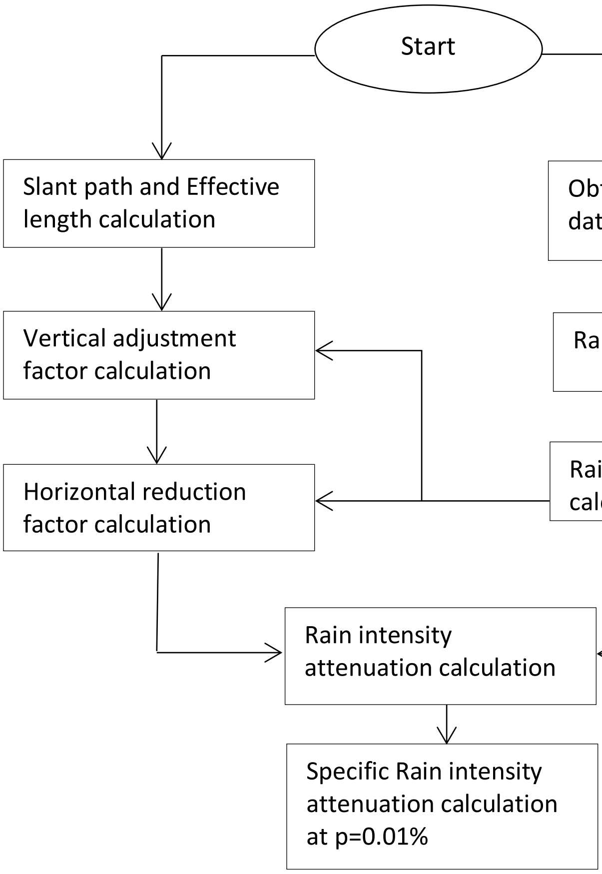

Fig. 1. Method of Rain depth Acquisition and Specific Rain intensity attenuation calculation

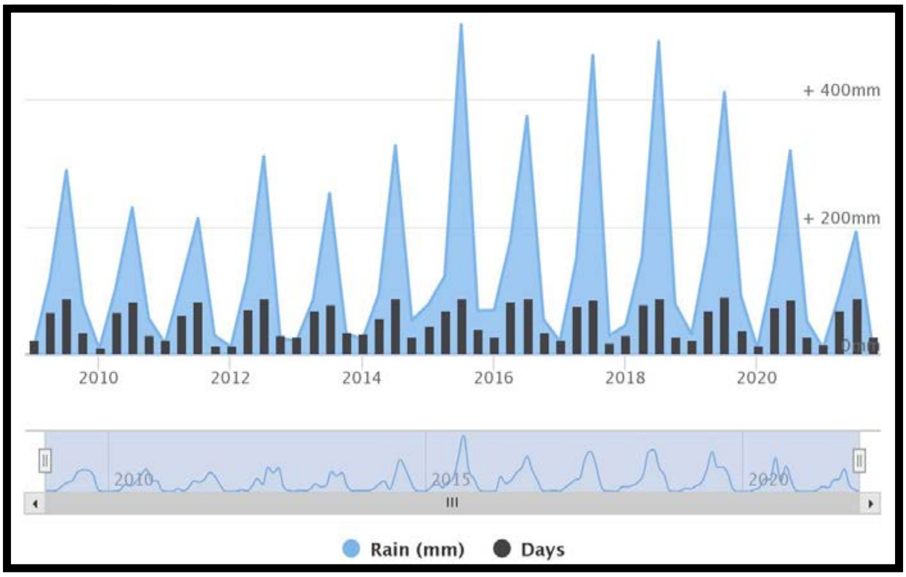

Fig. 2. yearly depths of rainfall in mm and rainy from 2010 to 2020

B. *Method of Data Collection*

This research is mainly secondary data collection source dependent. Thus, the ten years rainfall data employed for attenuation study were all obtained from the Nigerian Meteorological Agency (NIMET) branch, located in Lokoja. The ten years rainfall data ranged from January 2011 to December, 2020 was used in the study area. The ten years data contained monthly rainfall depth information which covers from January to December in each year. Such ten years data range was engaged to investigate and reveal the consistency of the impact of rain fall depth on the attenuation parameter values. To determine the rain attenuation values, first, the acquired yearly rain fall depth was divided by the rain duration. This was followed by incooperating computed rain intensity values into ITU rain models as described expression in equation (10). The rain height value used the attenuation study was expression in equation (9).

C. Specific attenuation due to Rain Estimation method

In this work, the Recommendation ITU-R P.838-3[27] is fully explored to obtain specific attenuation due to Rain and the implementation algorithm is structured in seven (7) stepwise approaches as provided below

Seven stepwise-approach implementation Algorithm

Step 1: Determine the rain height, H, and the slant path length, L_s, using the expression in equation (1) and (2), respectively:

$$H_r = H_o + 0.36 \tag{1}$$

$$L_s = \frac{(H_R - H_s)}{\sin\theta} \tag{2}$$

For θ < 5, L_s can be computed using:

$$L_s = \frac{2(H_R - H_s)}{\left(\sin^2\theta + \frac{2(H_R - H_s)}{R_e}\right)^{1/2} + \sin\theta} \tag{3}$$

Step 2: Determine the horizontal projection, L_h, in relation with the slant path length, L_s by:

$$L_h = L_s \cos\theta \tag{4}$$

Step 3: Determine the specific attenuation γ_R, using the Recommendation ITU-R P.838-3 model [27], in correspondence with the obtained empirical rainfall rate data $R_{0.01}$, using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{dB/km} \tag{5}$$

Step 4*:* Determine the horizontal reduction factor, $h_{0.01}$, and vertical adjustment factor, $v_{0.01}$ with respect to 0.01% percentage computation time constraint using the expressions in (6) and (7):

$$h_{0.01} = \frac{1}{1+0.78\sqrt{\frac{L_H\,\gamma_R}{f}} - 0.38\,(1-e^{-2L_H})} \tag{6}$$

$$\nu_{0.01} = \frac{1}{1+\sqrt{\sin\theta}\left(31\left(1-e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)}$$

$$L_R = \frac{L_G\,h_{0.01}}{\cos\theta}\ \text{km} \tag{7}$$

If | φ | < 36°, χ = 36 – | φ | degrees
Otherwise, χ = 0 degrees

Step 5: Obtain the effective path length, L_p using:

$$L_p = L_R\,\nu_{0.01} \tag{8}$$

Step 6*:* Determine predicted attenuation values in correspondence with the expressions in equations (5) and (8) at 0.01% percentage time constraint:

$$A_{0.01} = \gamma_R\,L_p \quad \text{dB} \tag{9}$$

Step 7*:* Finally, compute the overall specific attenuation, A_p at 0.01% percentage time constraint using:

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-C_1 - C_2 n(A_{0.01}) - \beta(1-p)\sin\theta)} \tag{10}$$

$$C_1 = 0.655 + 0.033\,ln(p) \tag{11}$$

$$C_1 = 0.045 \tag{12}$$

$p \geq 1\%$ or $| \varphi | \geq 36°$: $\beta = 0$

If $p < 1\%$ and $| \varphi | < 36°$ and $\theta \geq 25°$: $\beta = -0.005(| \varphi | - 36)$

Otherwise: $\beta = -0.005(| \varphi | - 36) + 1.8 - 4.25 \sin \theta$

The employed frequency dépendent coefficients, k and shown in Table 1.

Table 1. k and values for 3.5 frequency

Co-efficient	Frequency (3.5 GHz)
k	0.0002461
	1.2476

4. Results and Discussions

Firstly, here, table 2 is shown to provide the computed and categorized the rain intensity values into three parts, namely heavy rain intensity, very heavy rain intensity and extreme heavy rain intensity. The rain intensity values were obtained by dividing rain fall depth with the rain duration.

Secondly, in order to examine the rain intensity level trends over the investigation period (2011-2020), the graphs in figures 3 to 5 are plotted, using moving average technique. That is, by means of the moving average technique, the overall trend in the rain intensity dataset over the investigation period is clearly revealed. Figure 3, for example, heavy rain intensity levels depicts a decreasing trend within the ten years investigation period; but for figures 4 and five, a relative stable increasing trend levels is revealed by the moving average for intensity values due to very heavy rain and extreme heavy rain within the investigation period. This simply implies that more signal attenuation is expected in future years in the study location due to increasing heavy rain and extreme heavy rain level depths.

Table 2. Classified Rain Intensity due to Different Rain Depth

	Heavy Rain Intensity	Very Heavy Rain Intensity	Extreme Heavy Rain Intensity
2011	59.18	64.10	119.30
2012	35.46	63.88	91.98
2013	46.73	80.56	119.38
2014	20.23	77.01	90.00
2015	19.93	77.01	101.31
2016	39.73	60.00	118.23
2017	26.43	64.61	102.90
2018	12.66	87.00	122.15
2019	18.35	69.58	120.40
2020	30.60	83.03	90.00

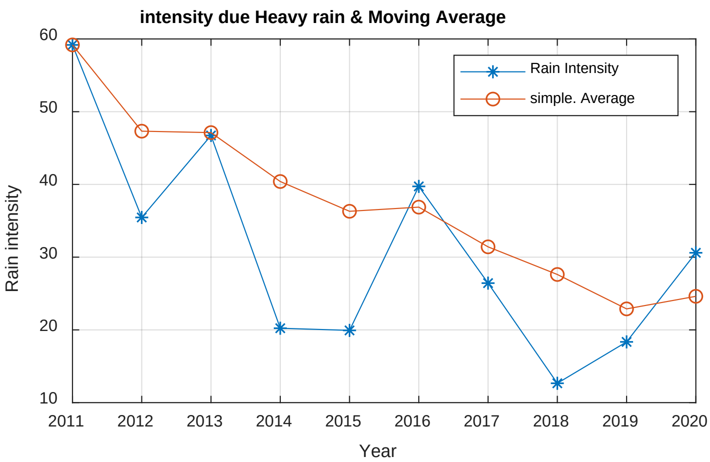

Fig. 3. Intensity level moving trend due to heavy rain from 2011 to 2020

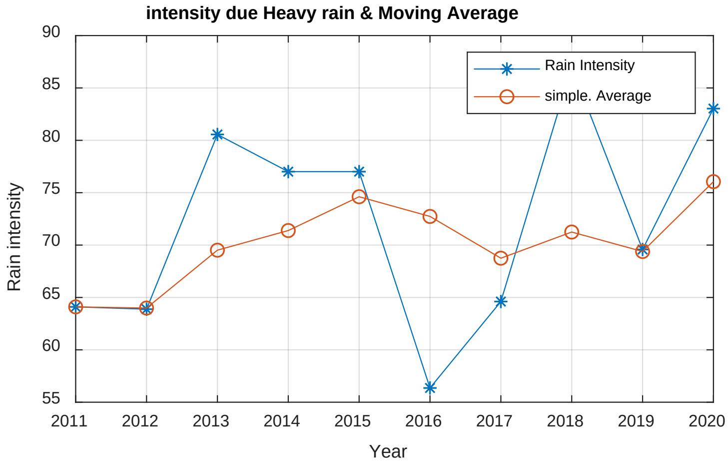

Fig. 4. Intensity level moving trend due to very heavy rain from 2011 to 2020

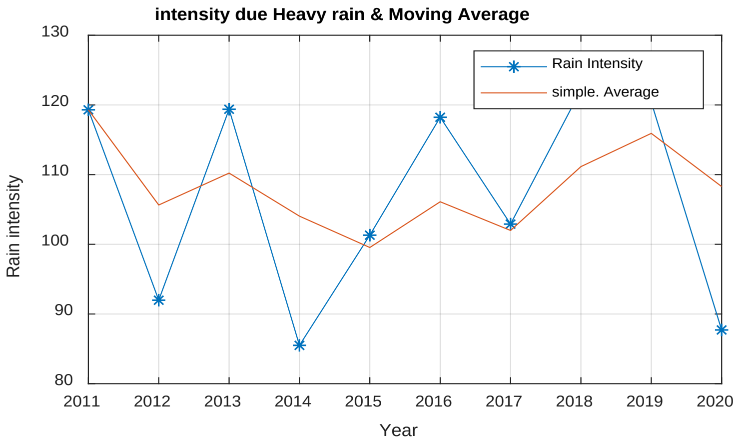

Fig. 5. Intensity level moving trend due to extreme heavy rain from 2011 to 2020

The specific attenuation values obtained by means of the classified rain depth/ rainfall intensity with the Recommendation ITU-R P.1511 are presented graphically are presented in this section as displayed in Figs. 6 to 15. Each graph revealed the attained attenuation levels based on ten years of rain depth data ranging from January 2010 to December 2020. The specific attenuation values of rain attenuation plotted against 0.01% percentage of time for an average year (mm/h).

Specifically, Fig. 6 provides a comparison of specific attenuation due to different rain intensity levels for 2011. Fig. 7 compares the specific attenuation due to different rain intensity levels for 2012. Fig. 8 provides a comparative analysis of Specific attenuation due to different rain intensities and levels for 2013. Fig. 9 provides a comparison of Specific attenuation due to different rain intensity levels for 2014. Fig. 11 provides a comparison of Specific attenuation due to different rain intensity levels for 2015. Similarly, Figs. 12-15 display of Specific attenuation due to different rain intensity levels for 2016-2020.

As can be seen, each graph reveals that the level of attenuation attained versus 0.01% percentage of time depends on the type of rain intensity levels (heavy rain, very heavy rain, extremely heavy rain), which in turn is dependent upon rain depth or rate drop sizes. For example, at 0.001 percent of the time in figure 6, the amount of specific attenuation for heavy rain is 2dB, while for very heavy and extremely heavy rain, the specific attenuation levels amount to 2.3dB and 4dB respectively. The same amount of specific attenuation due to different rain depths, can also be observed in Figs. 7-15. These different amounts of specific attenuation simplify implies that the heavier the rain, the more scattering and absorption of the propagated electromagnetic signals owing more, thus leading to degraded and higher the attenuation levels. Thus, noted in [[27-32], the availability of a network communication links or channels strongly rely on the depth of rain attenuation and rate of service outage occurrence in correspondence with recovery period for each outage. By means of Stroke Law [33], the scattering coefficient can be quantified using:

$$\beta_{sc} \ = \pi a^2 N_d Q_s \left(\frac{a}{\lambda}\right) \tag{13}$$

With a and N_d being the raindrop radius (0.001cm - 0.1cm) and Rain drop distribution. $\lambda$and Q_{sc} indicate the wavelength and scattering efficiency.

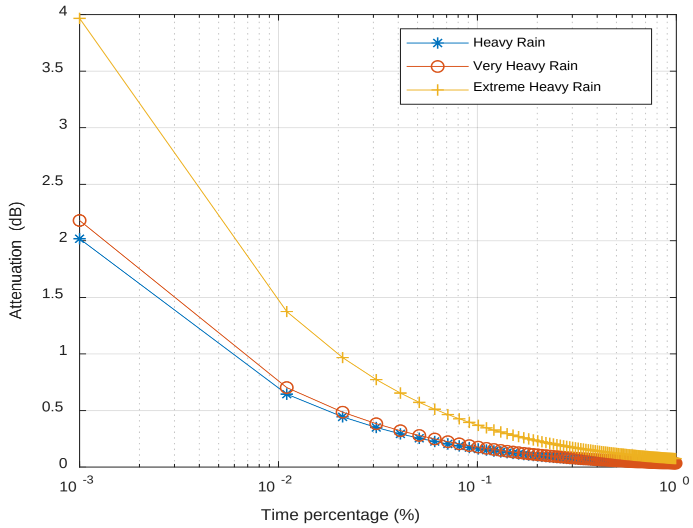

Fig. 6. Comparison Specific attenuation due different rain intensity level for 2011

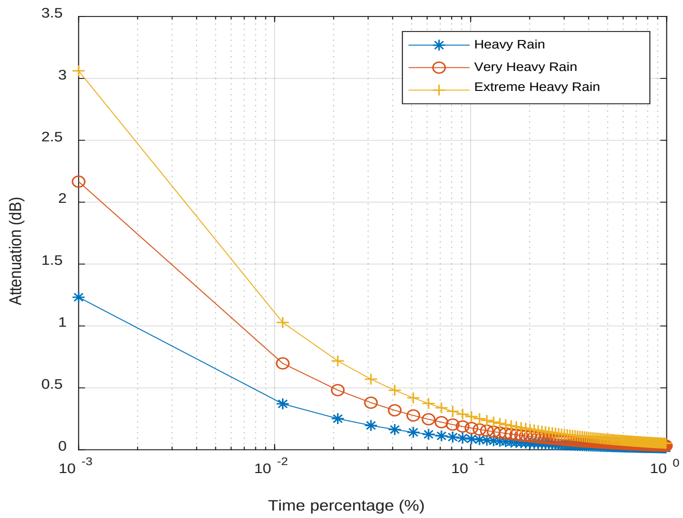

Fig. 7. Comparison Specific attenuation due different rain intensity level for 2012

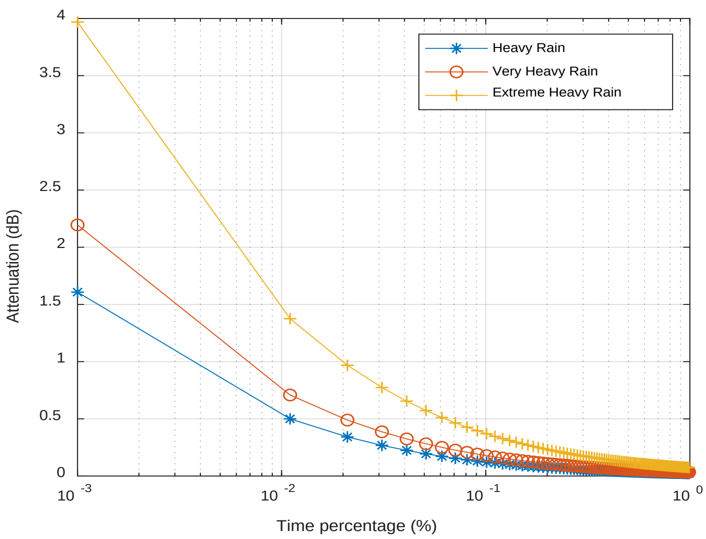

Fig. 8. Comparison Specific attenuation due different rain intensity level for 2013

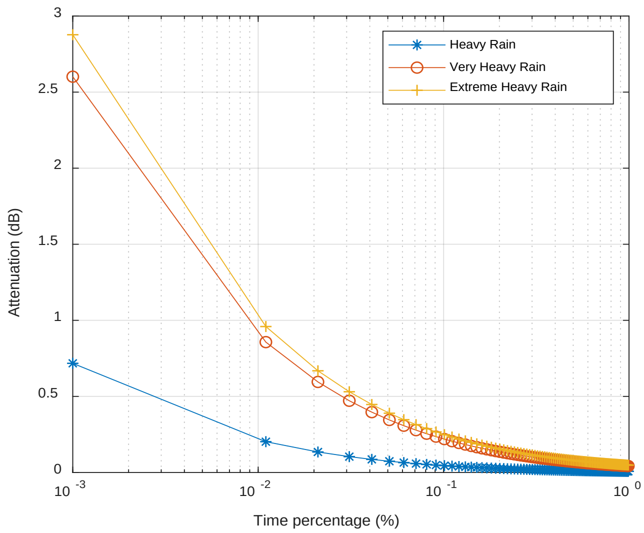

Fig. 9. Comparison Specific attenuation due different rain intensity level for 2014

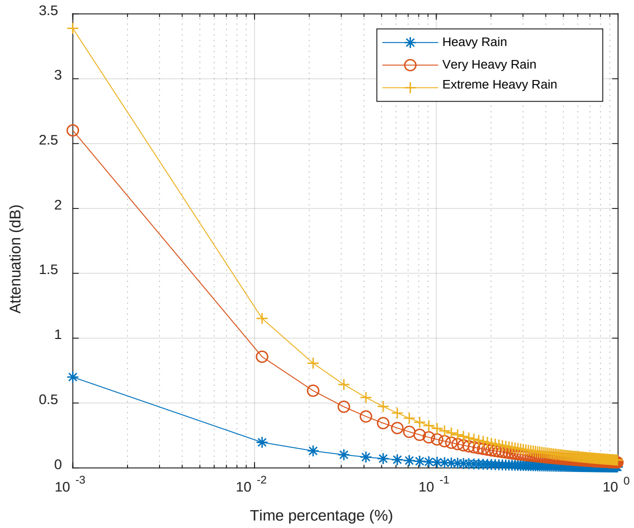

Fig. 10. Comparison Specific attenuation due different rain intensity level for 2015

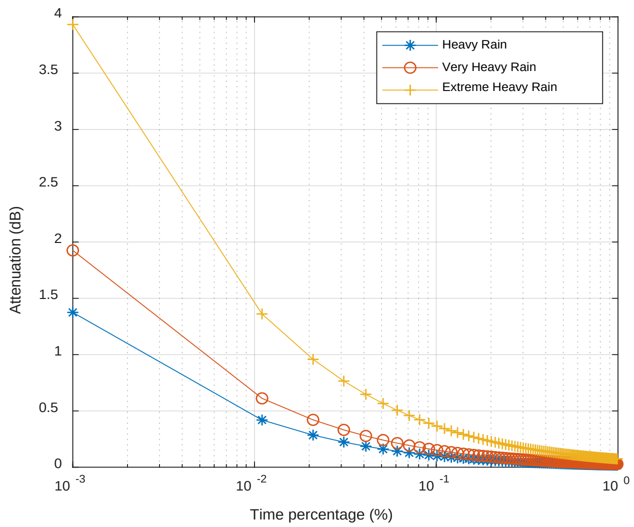

Fig. 11. Comparison Specific attenuation due different rain intensity level for 2016

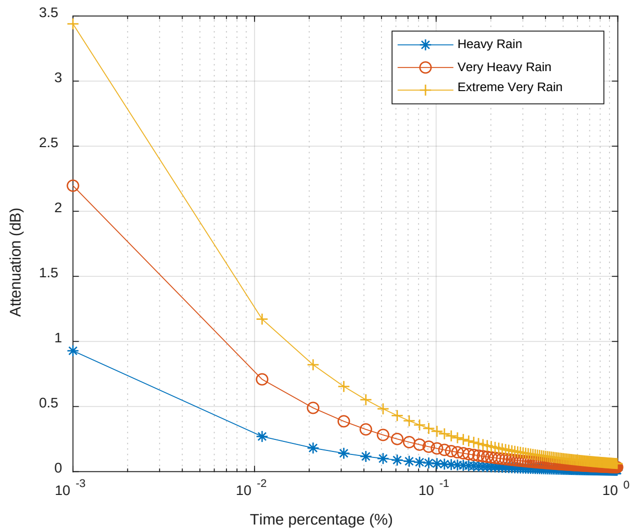

Fig. 12. Comparison Specific attenuation due different rain intensity level for 2017

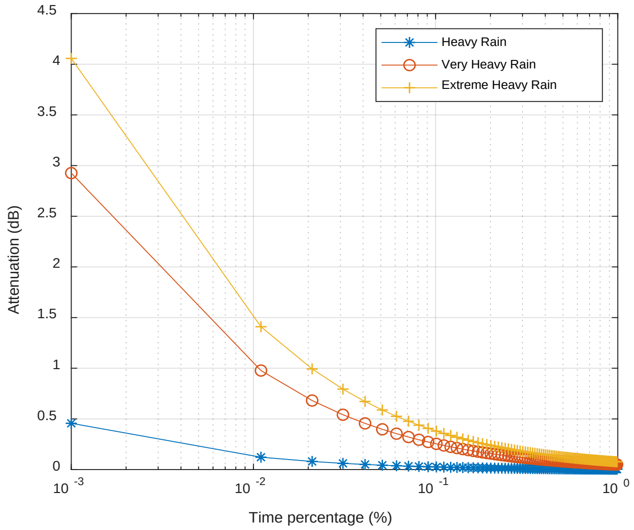

Fig. 13. Comparison Specific attenuation due different rain intensity level for 2018

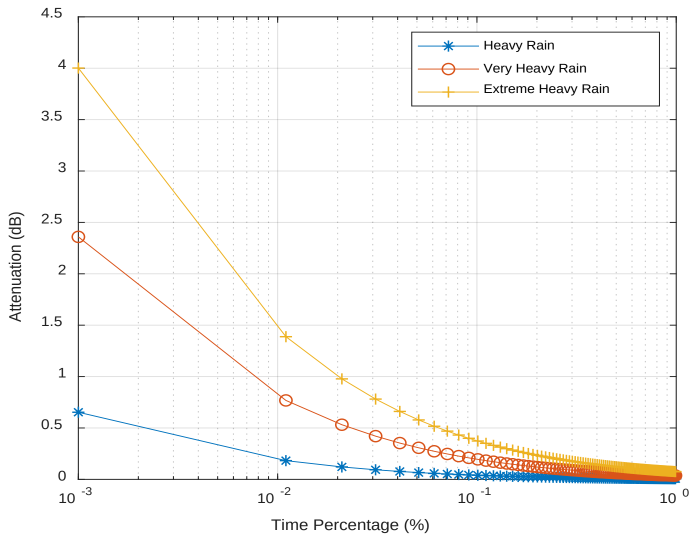

Fig. 14. Comparison Specific attenuation due different rain intensity level for 2019

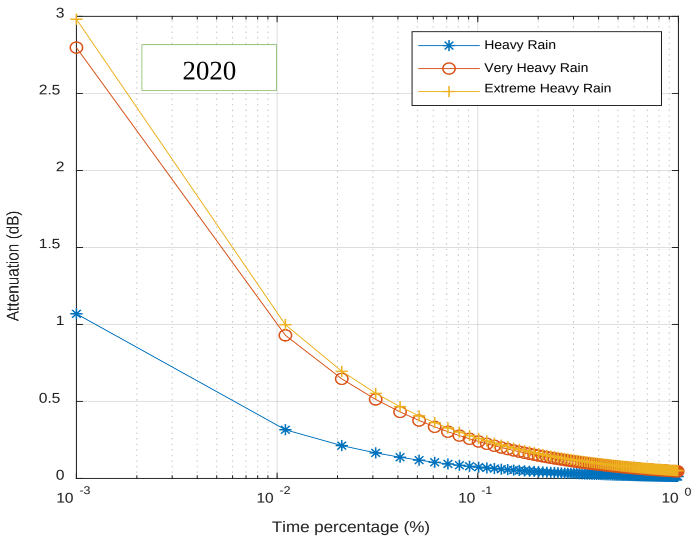

Fig. 15. Comparison Specific attenuation due different rain intensity level for 2020

5. Conclusion

Rain is a special form of liquid water that falls from clouds. The amount of rain that falls from the cloud at any point in time varies from one to another, depending upon seasonal variation, location, temperature, air masses movement and other factors. Although, there exist numerous positive effects of rainwater on both plants and animals on the earth, however, too much of it can be detrimental as well.

The paper's main objective was to perform an empirical based-rain attenuation quantification and impact analysis on 5G new radio networks at 3.5GHz broadband frequency in Nigeria. This has been achieved through the following contributions. Firstly, a ten-year of rainfall depths data have been acquired, categorized, and employed to examine their implicative intensity level trends over a period of the past ten years 3.5G transmission frequency. Secondly, the Recommendation ITU-R P. 1511-based model has explored to prognostically estimate and quantity the amount of specific attenuation loss due to the categorized rainfall depths over 3.5G transmission frequency, which has recently been proposed for 5G New Radio Broadband Networks deployment in Nigeria. The specific attenuation values of rain attenuation were shown graphically against 0.01% percentage of time for an average year (mm/h). The results reveal that the level of attenuation attained versus 0.01% percentage of time depends on the type of rain intensity levels (heavy rain, very heavy rain, extremely heavy rain), which in turn is dependent upon rain depth or rate drop sizes. For example, at 0.001 percent of the time, the amount of specific attenuation for heavy rain is 2dB, while for very heavy and extreme heavy rain, the specific attenuation levels amount to 2.3dB and 4dB respectively. These different amounts of specific attenuation simplify implies that the heavier the rain, the more scattering and absorption of the propagated electromagnetic signals owing more, thus leading to degraded and higher the attenuation levels.

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