Derived Specific Rain Attenuation at Stand-Alone Milimeter Wave Bands for Samaru Zaria, Nigeria

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ABSTRACT

This work studies rain–induced effect on some envisaged 5G links located at Samaru Zaria, Kaduna State, Nigeria, operating at 26 GHz, 38 GHz and 42 GHz in a MATLAB environment; using 3–year rain data obtained from Em60G™ datalogger–powered metrological setup of the Nigerian Metrological Agency (NiMet) located at Ahmadu Bello University, Zaria. Lavergnat and Gole (LG) model was used to derive the 1–minute rain rate statistics while monthly and annual cumulative distributions for both the rain gauge's 60–minute and the derived 1–minute rain rate statistics were comparably presented. The 1–minute rain rate curve was fitted into both Lognormal and Gamma distributions to approximate the low and high rainfall rates respectively, which was then used to derive the rain attenuation statistics using the Power–Law model. The specific rain attenuation for 0.001% exceedance probability was found to be 1.117 dB/km at 26 GHz, 2.698 dB/km at 38 GHz and 3.245 dB/km at 42 GHz. Similarly, for 0.01%, it was found to be 0.842 dB/km, 1.898 dB/km and 2.278 dB/km at 26 GHz, 38 GHz and 42 GHz respectively. Furthermore, for 0.1%, it was found to be 0.842 dB/km, 1.898 dB/km and 2.278 dB/km at 26 GHz, 38 GHz and 42 GHz respectively. Lastly, for 1%, it was derived to be 0.754 dB/km at 26 GHz, 1.698 dB/km at 38 GHz and 2.026 dB/km at 42 GHz.

1. INTRODUCTION

The mmWave are a part of the electromagnetic (EM) spectrum with frequency and wavelength ranges of 30 – 300 GHz and 10 – 1mm respectively. This class of the EM waves is considered as one of the key enablers of the fifth generation (5G) radio network technology, an advancement of the earlier radio network evolutions of second, third and fourth generations (2G, 3G and 4G) mobile networks, which unleashes huge potentials including but not limited to unprecedented high data rates at low latency that guarantees a paradigm shift in users experience [1, 4]. For the global deployment of the 5G technology, the ITU has suggested the use of frequency bands above 6 GHz. Likewise, Nigeria, even though still an upcoming deployer [2, 4], has through the Nigeria Telecommunications Commission (NCC), reserved 26 GHz, 38 GHz, and 42 GHz for 5G deployment in the country [1]. The mmWave are however, essentially susceptible to attenuation by climatic factors such as rain. For a tropical location like Nigeria, rainfall is essentially the most predominant climatic element that severely impairs terrestrial communication links operating at frequencies above 10 GHz and certainly, the most significant contributor to path loss at mmWave bands in 5G systems [2, 6, 17, 24]. Hence, consideration of this rain–effect for a specific geographical location is a critical requirement in terrestrial network planning [7, 16]. This rain-induced impairment, rain attenuation, is a function of the rain rate as well as raindrop size [2]. Nevertheless, the spatial and temporal variability of rain rate during a rainfall event makes determination of rain–induced attenuation very challenging, giving rise to many attempts that have occasioned a number of techniques aimed at estimating the one – minute rain rate required for the derivation of rain attenuation statistics [7, 8, 10, 15, 16, 17]. A key factor that determines the rain rate distribution of a location is the sampling, accumulation, averaging or integration time, denoting the interval between successive readings of the rain gauge. High – resolution rain gauge such as one with 1–minute integration time, is preferred owing to its ability to capture abrupt changes in the rain rate distribution of a location [7, 11, 13]. Unfortunately, Nigeria, just like many other tropical countries, faces dearth of one – minute rain data due to the capital – intensive nature of deploying the measurement setup [2]. For the few locations with deployed measuring equipment, only rainfall data with higher integration times than the required one minute are obtainable [2, 8, 9, 15, 16, 17], hence the need for conversion. Many conversion techniques to one– minute rain data have been put forward but Lavergnat and Gole (LG) model, which is based on [11], has been adjudged the best [7, 8, 13]. The 1–minute rain rate distribution is required for the determination of rain attenuation statistics for any specific location. Therefore, it is expedient that the rain attenuation statistics is considered in the planning of 5G network deployment for any envisaged deployment location. This work studies rainfall statistics for Samaru Zaria, Nigeria, using three years of 60 – minutes rain data observed from 2020 through 2022. The work further investigates the cumulative distributions, cumulative probability functions and exceedance probabilities, with a view to determining 1 –minute rain rate statistics and attenuation required for 5G network planning at the study location.

2. SITE DETAILS

The weather station is one of the installations of the Nigerian Metrological Agency (NiMet) located close to the School of Post Graduate (PG) Studies, ABU main campus, Samaru Zaria. The metropolitan Zaria, lies geographically between latitude 10.966667°N to 11.250000°N and longitude 7.550000°E to 7.766667°E [3, 12]. Being an automatic station, it is powered by METER Group – manufactured Em60G™ datalogger which records rainfall data on hourly basis [5, 18] as illustrated by Figure 2. An integral part of the setup, is the tipping bucket–type rain gauge with sensitivity of 0.5 mm/min, operational temperature in the range of -10 °C to 50 °C and 100% tipping accuracy [18]. Three – year (January 2020 through December 2022) rainfall data were obtained from the station directly through the datalogger as summarized by table 1 below.

Figure 1: Automatic rain measuring setup powered by Em60G™ datalogger

The retrieved rainfall data provides basis for the generation of rain rate statistics required for the derivation of rain attenuation statistics [7, 8, 10, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25].

Table 1: Measured monthly Rainfall (mm) for Zaria from year 2020 through 2022

Month/Year	**2020**	**2021**	**2022**
Jan	0	0	0
Feb	0	0	0
Mar	1.8	0	0
Apr	3.8	15.9	48.5
May	198.2	75.5	56
Jun	80.4	159.7	258
Jul	336.7	333.2	185.6
Aug	263.9	159.8	300.2
Sep	338.7	196.6	350.7
Oct	52	46.6	25.5
Nov	0	0	0
Dec	0	0	0

Previous studies have demonstrated that rain rate characteristics in northern Nigeria exhibit notable spatial and temporal variability, which must be accurately captured for reliable attenuation prediction at 26 GHz, 38 GHz, and 42 GHz [12], [16].

3. METHODOLOGY

3.1 Data Acquisition

Three years of 60 – minutes rain data observed from 2020 through 2022, was used in this work. The data was retrieved using a personal computer (PC) connected to an Em60G™ datalogger and exported in Microsoft Excel format to enable onwards preparation and processing into rain rate cumulative distribution (mm/hr), required for the derivation of rain attenuation statistics.

3.2 Derivation of Rain Attenuation

The exported raw rainfall data (mm) was processed into rainfall rate data (in mm/hr) using equation (1) as follows [14, 7]:

$$R\_D\ (\mathrm{mm/hr}) = \frac{(60 \times L(\mathrm{mm}))}{(T(\mathrm{min}))} \qquad 1$$

Where R_D is the rain rate at the rain – gauge's integration time, L is the peak rainfall in a monthly span of the dataset and T is the observation time over which the peak rainfall was experienced in a month. Lavergnat and Gole (LG) model was used to convert this rain rate into 1 minute integration time as against that obtained from the 60 minutes – integration time rain gauge. Lognormal and Gamma distributions were used to approximate the low and high rainfall rates, respectively, as is the trend especially in tropical regions [12The specific rain attenuation for the selected operational frequencies of 26 GHz, 38 GHz, and 42 GHz was computed using the ITU-R power-law relationship between specific attenuation and rain rate, as defined in Recommendation ITU-R P.838-3 [19]. Rain rate exceedance statistics were obtained in accordance with ITU-R P.837-7 [20], while terrestrial line-of-sight link assumptions followed ITU-R P.530-18 [21]. These recommendations have been extensively validated for mmWave frequencies and remain the reference framework for attenuation prediction in the 26–42 GHz range [22], [23], [25].

4 RESULTS AND DISCUSSION

From the results obtained as presented in Figures 2-3, it was shown that the total rainfall accumulations at Samaru Zaria were 1275.5 mm, 987.3 mm and 1224.5 mm in 2020, 2021 and 2022 respectively. The mean total annual rainfall accumulation was also derived to be 1162.4 mm. Furthermore, the highest monthly accumulation was recorded in September for year 2020 and 2022, while for 2021, highest monthly rainfall was experienced in July.

Figure 4 presents rain rate cumulative distributions for both 1–minute and 60–minutes integration times, while Figure 5 shows the annual rain rate probabilities of exceedance. Figure 6 presents the fitted cumulative distribution approximated using lognormal and gamma distributions.

Similarly, from the result presented in Figure 7, for 0.001% exceedance probability, the specific rain attenuation was found to be 1.117 dB/km at 26 GHz, 2.698 dB/km at 38 GHz and 3.245 dB/km at 42 GHz. While for 0.01% exceedance probability, the specific rain attenuation was found to be 0.842 dB/km, 1.898 dB/km and 2.278 dB/km at 26 GHz, 38 GHz and 42 GHz respectively. Similarly, for 0.1% probability of exceedance, the specific rain attenuation was derived to be 0.842 dB/km, 1.898 dB/km and 2.278 dB/km at 26 GHz, 38 GHz and 42 GHz respectively. Lastly, for 1% exceedance probability, the specific rain attenuation was also derived to be 0.754 dB/km at 26 GHz, 1.698 dB/km at 38 GHz and 2.026 dB/km at 42 GHz.

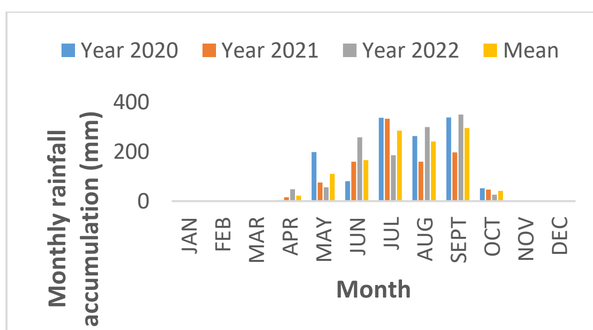

Figure 2: Cumulative monthly rainfall distribution at Zaria for 2020 through 2022 (mm)

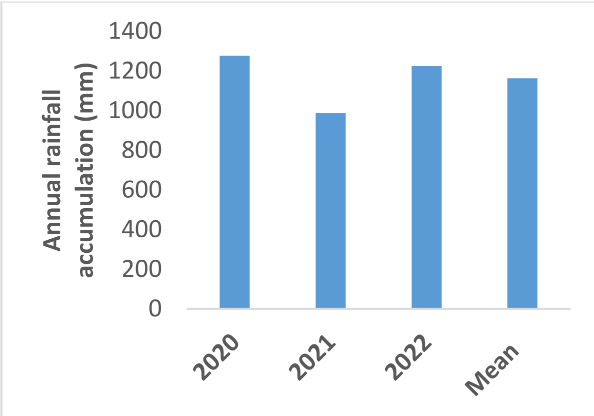

Figure 1: Cumulative annual rainfall distribution

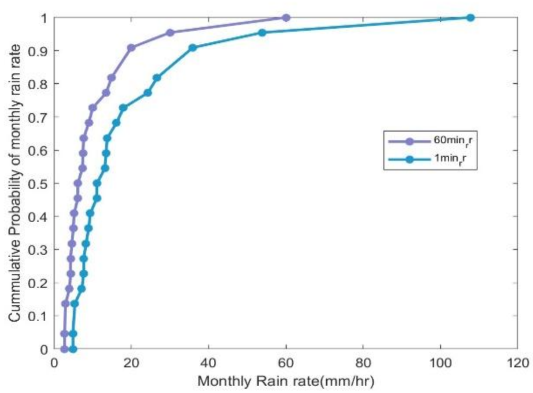

Figure 2:Cumulative Probability Distribution of rain rate at 1 – minute and 60 – minutes sampling times.

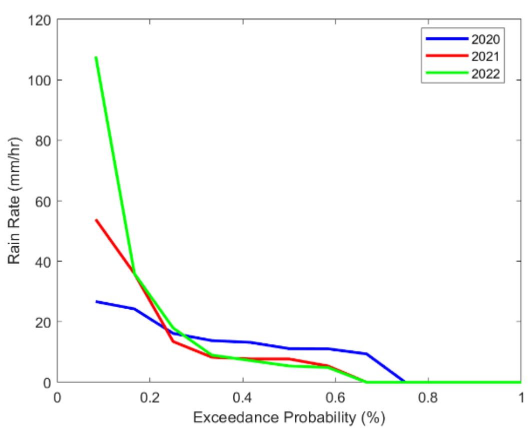

Figure 3:Rainfall Rate Annual Probability of Exceedance

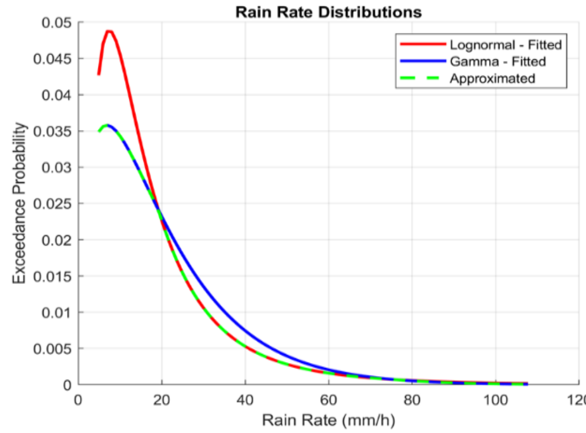

Figure 6: Fitted rain rate distribution curve

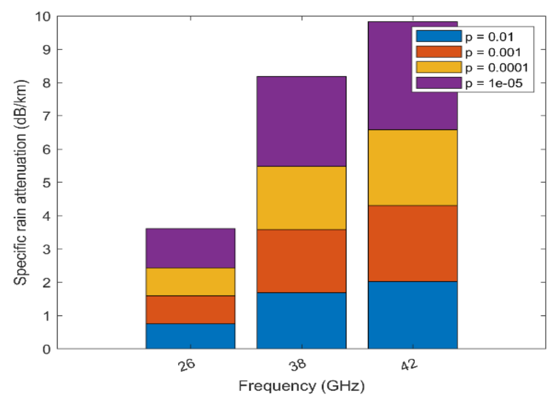

Figure 7: Specific rain attenuation at different frequencies of interest and exceedance probabilities derived from empirical datasets

The attenuation trends obtained at 26 GHz, 38 GHz, and 42 GHz are consistent with earlier Nigerian and tropical-region studies, which report a sharp increase in rain attenuation severity with frequency [7, 14, 18, 25]. However, the results further highlight location-dependent variations in attenuation magnitude, underscoring the need for site-specific modelling when designing 5G mmWave links in tropical environments [2], [17], [23].

5 CONCLUSION

In this study, investigation into the effect of rain on some envisaged 5G links at the mmWave–based 5G bands of 26 GHz, 38 GHz and 42 GHz; has been carried out in a MATLAB environment using 3 – year rainfall data, with a view to providing information that can help 5G deployment in Nigeria. Rain rates exceeded (mm/hr) at the rain-gauge's (60–minute) and 1–minute integration times, as well as the corresponding specific rain attenuation (dB/km) at 0.001%, 0.01%, 0.1% and 1% for Samaru Zaria have been presented. From the results, rain rates have been shown to increase inversely with both integration time and exceedance probability. Also, specific rain attenuation has been shown to increase proportionately with rain rate, exceedance probability and operating frequency.

REFERENCES

[1] C. K. Agubor, N. Chukwuchekwa, and L. S. Ezema, "5G network deployment in Nigeria: Key challenges and the way forward," *Eur. J. Eng. Technol. Res.*, vol. 6, no. 3, pp. 16–19, 2021, doi: 10.24018/ejers.2021.6.3.2068.

[2] E. Alozie *et al.*, "A review on rain signal attenuation modelling, analysis and validation techniques: Advances, challenges and future direction," *Sustainability*, vol. 14, no. 18, p. 11744, 2022, doi: 10.3390/su141811744.

[3] S. Badamasi, B. A. Sawa, and M. L. Garba, "Groundwater potential zones mapping using remote sensing and GIS techniques in Zaria, Kaduna State, Nigeria," *Am. Sci. Res. J. Eng. Technol. Sci.*, vol. 24, no. 1, pp. 51–62, 2016.

[4] P. Curwen and J. Whalley, "5G progress in the Americas, Asia, the Middle East and Africa," in *Understanding 5G Mobile Networks*. Bingley, U.K.: Emerald Publishing, 2021, pp. 89–112.

[5] Y. Dong, S. Miller, and L. Kelley, "Performance evaluation of soil moisture sensors in coarse- and fine-textured agricultural soils," *Agriculture*, vol. 10, no. 12, p. 598, 2020.

[6] S. K. Hinga and A. A. Atayero, "Deterministic 5G mmWave large-scale 3D path loss model for Lagos Island, Nigeria," *IEEE Access*, vol. 9, pp. 134270–134288, 2021.

[7] O. Ibe, "Attenuation of radio communication signals by rain at millimeter-wave bands at selected locations in Nigeria," Ph.D. dissertation, Dept. Elect. Eng., Univ. Nigeria, Nsukka, Nigeria, 2021.

[8] E. C. Ibekwe, K. C. Igwe, and J. O. Eichie, "Rain attenuation prediction for 5G communication links in Minna, Nigeria," *J. Phys.: Conf. Ser.*, vol. 2034, no. 1, p. 012028, 2021.

[9] K. C. Igwe, O. D. Oyedum, M. O. Ajewole, A. M. Aibinu, and J. A. Ezenwora, "Performance evaluation of rain rate conversion models for microwave propagation studies," *Adv. Space Res.*, vol. 67, no. 10, pp. 3098–3105, 2021.

[10] A. R. M. M. Itamba, "Monthly variability of radio-wave propagation effects on satellite links operating at 20 GHz," M.Sc. thesis, Dept. Elect. Eng., Univ. Dar es Salaam, Tanzania, 2022.

[11] J. Lavergnat and P. Golé, "A stochastic raindrop time distribution model," *J. Appl. Meteorol. Climatol.*, vol. 37, no. 8, pp. 805–818, 1998.

[12] J. Ojo, M. Ajewole, and S. Sarkar, "Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria," *Prog. Electromagn. Res. B*, vol. 5, pp. 207–223, 2008.

[13] J. S. Ojo, A. K. Adenugba, and A. T. Adediji, "Dynamical model for deriving 1-min rain rate from various integration times in a tropical region," *J. Telecommun. Syst. Manag.*, vol. 5, no. 1, pp. 1–5, 2016.

[14] J. E. Olubusade *et al.*, "Rain-induced attenuation on terrestrial paths at Ku, K and Ka bands over Akungba-Akoko, Nigeria," *Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 145–152, 2018.

[15] O. O. Ometan *et al.*, "Six years of rainfall rate measurement at Covenant University, Southwest Nigeria," *J. Phys.: Conf. Ser.*, vol. 1299, no. 1, p. 012061, 2019.

[16] T. V. Omotosho and C. O. Oluwafemi, "One-minute rain rate distribution in Nigeria derived from TRMM satellite data," *J. Atmos. Sol.-Terr. Phys.*, vol. 71, no. 5, pp. 625–633, 2009.

[17] M. A. Samad, F. D. Diba, and D. Y. Choi, "A survey of rain attenuation prediction models for terrestrial links—State of the art and research challenges," *Sensors*, vol. 21, no. 4, p. 1207, 2021.

[18] A. I. O. Yussuff and K. Momoh, "Performance evaluation of rain attenuation prediction models at coastal locations at 12 and 40 GHz," *Glob. J. Earth Environ. Sci.*, vol. 6, no. 2, pp. 27–37, 2021.

[19] ITU-R, "Specific attenuation model for rain for use in prediction methods," *Rec. ITU-R P.838-3*, Geneva, Switzerland, 2005.

[20] ITU-R, "Characteristics of precipitation for propagation modelling," *Rec. ITU-R P.837-7*, Geneva, Switzerland, 2017.

[21] ITU-R, "Propagation data and prediction methods required for terrestrial line-of-sight systems," *Rec. ITU-R P.530-18*, Geneva, Switzerland, 2021.

[22] L. Luini and C. Capsoni, "Rain attenuation at millimeter-wave frequencies: Experimental results and modelling," *IEEE Trans. Antennas Propag.*, vol. 61, no. 1, pp. 435–443, 2013.

[23] S. Kumar and A. Chandra, "Rain attenuation modeling for 5G millimeter-wave links in tropical regions," *Wireless Pers. Commun.*, vol. 117, pp. 1825–1843, 2021.

[24] A. Abouelseoud and H. Elragal, "Impact of rain attenuation on 5G mmWave systems," *Int. J. Commun. Syst.*, vol. 33, no. 15, e4556, 2020.

[25] M. D. Yusof, M. R. Islam, and J. Din, "Rain attenuation prediction at millimeter-wave bands in tropical climates," *Radioengineering*, vol. 29, no. 2, pp. 310–318, 2020.