COMPARISON OF OPTIMAL PATH LENGTH OF KU-BAND MICROWAVE COMMUNICATION LINK IN VARIOUS NIGERIAN CITIES WITH DIFFERENT ANNUAL MEAN ACCUMULATED RAINFALL DATA

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***Abstract*— In this paper, comparison of optimal path length of Ku-band microwave communication links located in various Nigerian cities with different annual mean accumulated rainfall data is presented. An analytical expression was used to convert the available rain volume data in mm per year to rainfall rate of one minute integration time at 0.01 %. A seeded Regular Falsi iteration method was used to determine the effective transmission range along with the effective propagation loss and other salient link parameters. A Mathlab program was written for the seeded Regular Falsi and then used for the actual computation of the link effective parameters of a case study communication link located in the selected cities across Nigeria. A sample simulation result for the city of Katsina with rain rate of 72.9 mm/hr shows that the numerical iteration converged at the 10th cycle with an error tolerance of 3.14 x10^{-06}. Comparison of the results for the selected cities across Nigeria showed that the city of Calabar has the highest rain rate, $R_{0.01}$ of 151 mm/hr and that lowest effective transmission range of 1.91 km. On the other hand, the city of Katsina has the lowest rain rate , $R_{0.01}$ of 72.9 mm/hr and that highest effective transmission range of 2.83 km. The implication of the results is that for Calabar city, it will require additional equipment or resources to ensure adequate coverage of a given area when compared to the coverage area of the same network in any of the other cities considered.**

Keywords*— *Microwave Communication, Transmission Range, Ku-Band Microwave, Optimal Transmission Range, Communication Link, Rain Fading, Fade Depth

I. INTRODUCTION

Generally, it is known that the Ku-band microwave frequency is seriously affected by rain attenuation [1,2,3,4,5,6,7,8,9]. As such, microwave link designers using the Ku-band pay attention to the potential rain fade depth in the coverage area of the network. Among other things, the rain fade depth will affect the maximum Path length of such Ku-band network. Again, the maximum transmission rage will vary from place to place based on their prevalent rain data [6, 7].

In addition, the maximum path length is also affected by the pathloss in the network coverage area. Specifically, different path loss models will present different pathloss values for different propagation area categories, such as urban, suburban and rural areas and even vegetation covered areas [10,11,12,13,14,15].

Consequently, in this paper, the focus is to use Hata path loss model for (large city) urban area along with rain fade depth to determine the effective or optimal Path length for selected Nigerian cities with different annual mean accumulated rainfall data. The study will show how the effective coverage area of microwave Ku-band network is affected by the annual mean accumulated rainfall data across the selected cities. The paper seek to show how much adjustments in terms of number of hops or transmission power the designer need to make in order to cover a certain set coverage distance. The Hata model for urban area is presented along with the requisite rain data. Also, the flowchart of a seeded Regular Falsi numerical iteration method [16,17,18,19,20] used for the computation of the effective transmission rang is presented. A sample Ku-band link parameters are used for numerical example.

II. METHODOLOGY

A. RAIN DATA

The study utilized annual mean accumulated rainfall data of twenty cities in Nigeria, as shown in Table 1. Particularly, the data was rain volume data in mm per year which then was converted to rainfall rate of one minute integration time at 0.01% using the analytical expression 21,22];

$$R_{0.01} = 4.866M^{0.431} \qquad (1)$$

where M is the annual mean accumulated rainfall volume in mm and $R_{0.01}$ is the one-minute integration time rain rates at 0.01% exceedance.

Table 1 : The annual mean accumulated rainfall data of twenty cities in Nigeria

S/N	City Name	Longitude	Latitude	Annual Mean Accumulated Rain (mm)
1	Kaduna	7.45	10.60	1266.4
2	Kano	8.20	12.05	629.0
3	Bauchi	9.82	10.28	1051.4
4	Jos	8.75	9.87	1306.2
5	Sokoto	5.25	13.02	676.1
6	Poriskum	11.03	11.70	633.2
9	Maiduguri	13.08	11.85	611.6
10	Katsina	7.68	13.02	533.9
11	Yola	12.47	9.23	992.3
12	Ikeja	3.33	6.58	1465.6
13	Ibadan	3.90	7.43	1397.1
14	Ondo	4.83	7.10	1660.1
15	Port Harcourt	7.02	4.85	2397.2
16	Owerri	7.00	5.48	2383.9
17	Calabar	8.35	4.97	2891.8
18	Markurdi	8.53	7.73	1276.2
19	Oshogbo	4.58	7.78	1321.1
20	Ikorin	4.58	8.48	1249.0
21	Lokoja	6.73	7.78	1310.6

Source:[21])

B. Hata Pathloss Model for (large city) urban area

Hata Path loss model for (large city) urban area is given as [23,24,25,26];

$$LP_{HATAU} = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) + (44.9 - 6.55 * \log_{10}(h_b)) * \log_{10}(d) \quad (2)$$

Where the correction factor for antenna height-gain, $a(h_m)$ for large city, $a(h_m)$ is give as;

$$a(h_m) = \begin{cases} 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \;\; for\ large\ city\ \ f \\ 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \;\; for\ large\ city\ \ f \end{cases} \quad (3)$$

- frequency , f is in MHz ; path length d is in km
- 150 MHz≤ f≤ 1000MHz; 30m ≤h_b ≤ 200m ;1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km

C. Path length with Hata Path loss model for Urban Area

The potential maximum path length of a wireless communication link based on Hata Path Loss can be found using the link budget equation;

$$P_R = P_T + (G_T + G_R) - LP_{HATAU} \quad (4)$$

where;

d is the path length

P_R = Received Signal Power (dBm)

P_T = Transmitter Power Output (dBm)

G_T = Transmitter Antenna Gain (dBi)

G_R = Receiver Antenna Gain (dBi)

$\mathrm{LP_{HATAU}}$ = Path loss based on Hata model for urban area

Effective Received Power ($\mathrm{P_{ReHAT}}_{AU}$) is given as:

$$\mathrm{P_{ReHAT}}_{AU} = \mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R} - \mathrm{LP_{HATAU}} \quad (5)$$

Effective Fade Margin ($\mathrm{fm_{eHAT}}_{AU}$) is given as:

$$\mathrm{fm_{eHAT}}_{AU} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - \mathrm{LP_{HATAU}} - P_S \quad (6)$$

Where

P_S is the receiver sensitivity in dB

D. Effective Fade Depth for microwave communication link Based On Free Space Path Loss model and rain fading

The rain fade depth ($fd_{me\mathrm{HAT}AU}$) at a path length ($d_{e\mathrm{HAT}AU}$) is given as;

$$fd_{me\mathrm{HAT}AU} = \max\left(\left(\mathrm{K_v}\left(\mathrm{R_{po}}\right)^{\alpha_\mathrm{v}}\right) * d_{e\mathrm{HAT}AU}, \left(\mathrm{K_h}\left(\mathrm{R_{po}}\right)^{\alpha_\mathrm{h}}\right) * d_{e\mathrm{HAT}AU}\right) \quad (7)$$

where:

k_h, α_h are horizontal polarization frequency dependent coefficients .

kv, $\alpha_{,v}$ are vertical polarization frequency dependent coefficients.

$\langle \gamma_{R_{po}} \rangle_h$ is the horizontal polarization rain attenuation per

$\langle \gamma_{R_{po}} \rangle_v$ is the vertical polarization rain attenuation per kilometer

po is the Percentage outage time (or Percentage unavailability time) of the link.

The path length, becomes optimal when $\mathrm{fm_{eHAT}}_{AU} = fd_{me\mathrm{HAT}AU}$. The seeded Regular Falsi iteration flowchart for the calculation of the optimal path length for various rainfall data is presented in Figure 1.

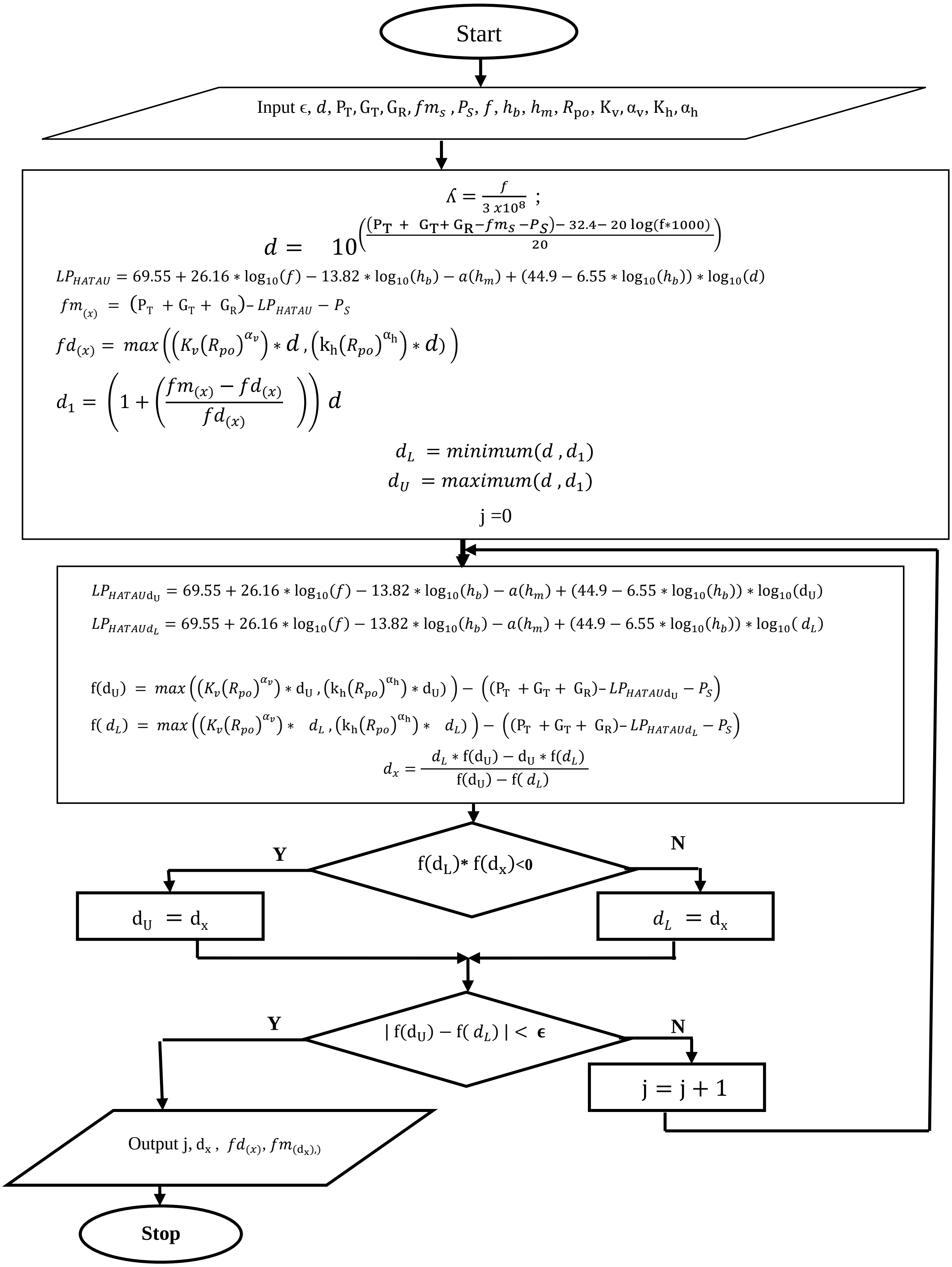

Figure 1: The seeded Regular Falsi iteration flowchart for the calculation of the optimal path length for various rainfall data

III. RESULTS AND DISCUSSION

A Mathlab program was written for the seeded Regular Falsi iteration flowchart in Figure 1and the program was implemented using the data in Table 2, which is a sorted version of the annual mean accumulated rainfall data of twenty cities in

Nigeria, as presented earlier in Table 1. The wireless communication link parameter values used for the simulation are shown in Table 3. The link is in the Ku-band of microwave frequency. A sample simulation result for the city of Katsina with rain rate of 72.9 mm/hr is shown in Table 4. The results in Table 4 shows that the numerical iteration converged at the 10th cycle with an error tolerance of 3.14 $\times 10^{-06}$. Comparison of the results of the numerical iteration for optimal transmission range for the selected cities across Nigeria is shown in Table 5 while the normalized rain rate and normalized effective transmission range for the various cities considered in the study are shown in Table 6 and Figure 2. The results showed that the city of Calabar has the highest rain rate, $R_{0.01}$ of 151 mm/hr and that lowest effective transmission range of 1.91 km. On the other hand, the city of Katsina has the lowest rain rate , $R_{0.01}$ of 72.9 mm/hr and that highest effective transmission range of 2.83 km. This corresponds with the results in Table 5 which show that the effective fade depth is directly proportional to the rain rate, $R_{0.01}$.

The implication of the results is that for Calabar city, it will require additional equipment or resources to ensure adequate coverage of a given area when compared to the coverage area of the same network in any of the other cities considered.

Table 2 The computed rainfall rate of one minute integration time at 0.01% (that is, R0.01 in mm/hr) for the selected cities in Nigeria and arranged in ascending order of R0.01

S/N	City Name	R0.01 (mm/hr)	S/N	City Name	R0.01 (mm/hr)	S/N	City Name	R0.01 (mm/hr)
1	Katsina	72.9	8	Ikorin	105.1	14	Ibadan	110.3
2	Maiduguri	77.3	9	Kaduna	105.8	15	Ikeja	112.6
3	Kano	78.2	10	Markurdi	106.1	16	Ondo	118.9
4	Poriskum	78.5	11	Jos	107.2	17	Owerri	138.9
5	Sokoto	80.7	12	Lokoja	107.3	18	Port Harcourt	139.3
6	Yola	95.2	13	Oshogbo	107.7	19	Calabar	151
7	Bauchi	97.6						

Table 3 The Wireless Communication link parameter values used for the simulation

Parameter Name and Unit	Parameter Value		Parameter Name and Unit	Parameter Value
f (MHz)	11000		**kh**	0.01772
Transmitter power, P_T(dB)	10		**ah**	1.214
Transmitter antenna Gain, G_T(dB)	25		**kv**	0.01731
Receiver antenna gain, G_R(dB)	25		**av**	1.1617
Receiver sensitivity, P_s (dB)	-84		**Percentage Availability, Pa (%)**	99.99
Fade Margin (dB)	10		**Rain Rate at 0.01 % outage probability, R0.01 mm/hr**	65

Table 4 The simulation results for the city of Katsina with rain rate of 72.9 mm/hr

Iteration Cycle	Transmission Range	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
0	4.0000	140.0218	-80.0218	3.9782	12.9382	8.96E+00
1	3.0663	136.0498	-76.0498	7.9502	9.9181	1.97E+00
2	2.8818	135.1227	-75.1227	8.8773	9.3215	4.44E-01
3	2.8412	134.9106	-74.9106	9.0894	9.1901	1.01E-01
4	2.8321	134.8624	-74.8624	9.1376	9.1605	2.29E-02
5	2.8300	134.8514	-74.8514	9.1486	9.1538	5.19E-03
6	2.8295	134.8489	-74.8489	9.1511	9.1523	1.18E-03
7	2.8294	134.8484	-74.8484	9.1516	9.1519	2.68E-04
8	2.8294	134.8482	-74.8482	9.1518	9.1518	6.08E-05
9	2.8294	134.8482	-74.8482	9.1518	9.1518	1.38E-05
10	2.8294	134.8482	-74.8482	9.1518	9.1518	3.14E-06

Table 5 Comparison of the results of the numerical iteration for optimal transmission range for the selected cities across Nigeria

S/N	City Name	Rain Rate	Convergence Cycle	Transmission Range	Propagation Loss by Hata Urban Model	Received Power	Effective Fade Margin	Effective Rain Fade Depth	Error
1	Katsina	72.9	8	2.83	134.85	-74.85	9.15	9.15	6.08E-05
2	Maiduguri	77.3	8	2.75	134.44	-74.44	9.56	9.56	8.55E-05
3	Kano	78.2	8	2.74	134.36	-74.36	9.64	9.64	9.12E-05
4	Poriskum	78.5	8	2.73	134.33	-74.33	9.67	9.67	9.31E-05
5	Sokoto	80.7	9	2.70	134.13	-74.13	9.87	9.87	2.58E-05
6	Yola	95.2	9	2.48	132.90	-72.90	11.10	11.10	5.98E-05
7	Bauchi	97.6	9	2.45	132.70	-72.70	11.30	11.30	6.69E-05
8	Ikorin	105.1	9	2.36	132.12	-72.12	11.88	11.88	9.10E-05
9	Kaduna	105.8	9	2.35	132.06	-72.06	11.94	11.94	9.34E-05
10	Markurdi	106.1	9	2.34	132.04	-72.04	11.96	11.96	9.45E-05
11	Jos	107.2	9	2.33	131.96	-71.96	12.04	12.04	9.83E-05
12	Lokoja	107.3	9	2.33	131.95	-71.95	12.05	12.05	9.87E-05
13	Oshogbo	107.7	10	2.33	131.92	-71.92	12.08	12.08	2.66E-05
14	Ibadan	110.3	10	2.30	131.72	-71.72	12.28	12.28	2.94E-05
15	Ikeja	112.6	10	2.27	131.55	-71.55	12.45	12.45	3.18E-05
16	Ondo	118.9	10	2.20	131.10	-71.10	12.90	12.90	3.91E-05
17	Owerri	138.9	10	2.01	129.76	-69.76	14.24	14.24	6.50E-05
18	Port Harcourt	139.3	10	2.01	129.73	-69.73	14.27	14.27	6.56E-05
19	Calabar	151	10	1.91	129.01	-69.01	14.99	14.99	8.22E-05

Table 6 The normalized rain rate and normalized effective transmission range for the various cities considered in the study

City Name	Normalized Rain Rate ~~(%)~~	Normalized Transmission Range (%)
Katsina	100.0	148.2
Maiduguri	106.0	144.0
Kano	107.3	143.5
Poriskum	107.7	142.9
Sokoto	110.7	141.4
Yola	130.6	129.8
Bauchi	133.9	128.3
Ikorin	144.2	123.6
Kaduna	145.1	123.0
Markurdi	145.5	122.5
Jos	147.1	122.0
Lokoja	147.2	122.0
Oshogbo	147.7	122.0
Ibadan	151.3	120.4
Ikeja	154.5	118.8
Ondo	163.1	115.2
Owerri	190.5	105.2
Port Harcourt	191.1	105.2
Calabar	207.1	100.0

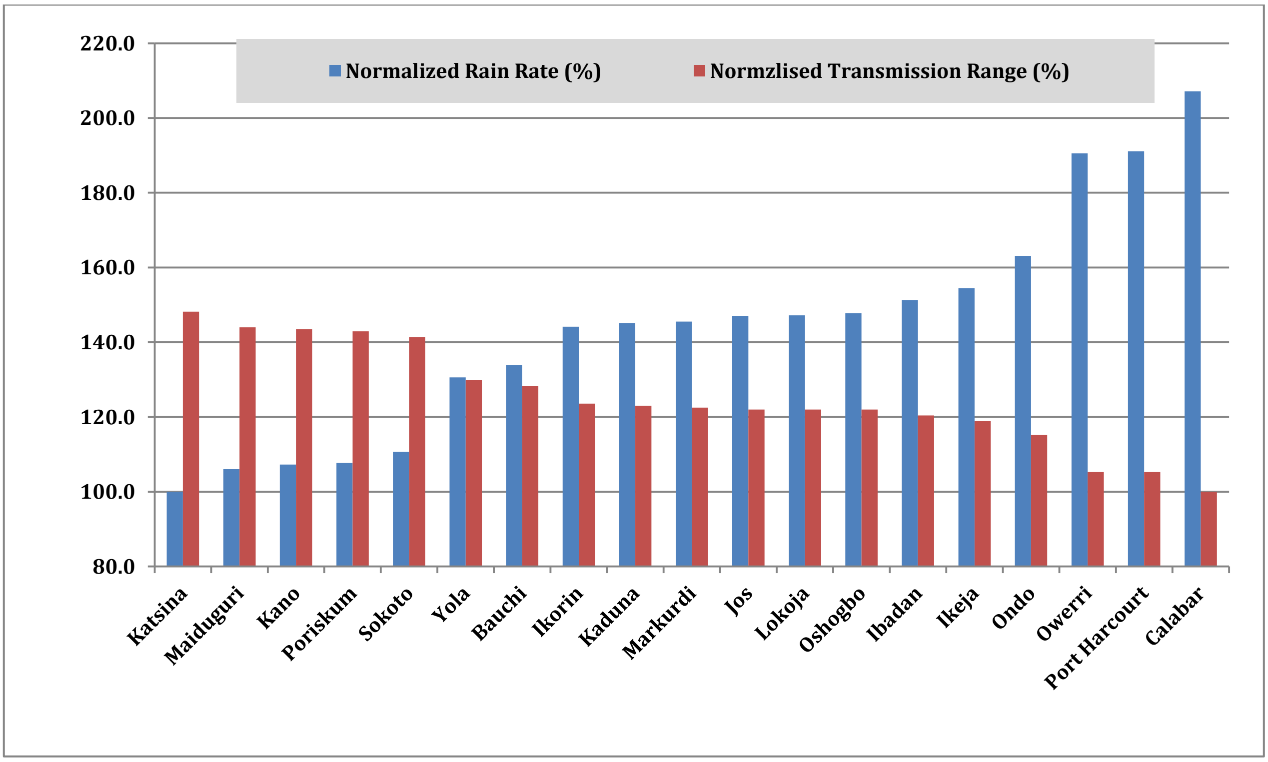

Figure 2 The bar charts of the normalized rain rate and normalized effective transmission range for the various cities considered in the study

IV. CONCLUSION

Computation of effective transmission range, the effective fade depth and other salient link parameters are computed for Ku-band microwave communication link in various Nigerian cities with different annual mean accumulated rainfall data. The essence of the study is to evaluate the effect of rain rate on the effective transmission range of microwave links installed in various cities across Nigeria. The results showed that among the cities considered, Calabar has the highest rain rate and the lowest transmission range whereas, Katsina has the lowest rain rate and the highest effective transmission range. In all, the study noted that higher rain rate amounts to higher fade depth which leads to lower effective transmission range. Lower transmission range however means that more network resources need to be deployed to ensure effective coverage of a given area that requires multi-hop communication link.

REFERENCES

1. Kestwal, M. C., Joshi, S., & Garia, L. S. (2014). Prediction of rain attenuation and impact of rain in wave propagation at microwave frequency for tropical region (Uttarakhand, India). *International Journal of Microwave Science and Technology*, *2014*.
2. Panchal, P., & Joshi, R. (2016). Performance analysis and simulation of rain attenuation models at 12–40 GHz band for an earth space path over Indian cities. *Procedia Computer Science*, *79*, 801-808.
3. Ozuomba Simeon, Henry Akpan Jacob and Kalu Constance (2019) Analysis Of Single Knife Edge Diffraction Loss For A Fixed Terrestrial Line-Of-Sight Microwave Communication Link Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. xx Issue xx, xxxx – 2019
4. Ojo, J. S., Ajewole, M. O., & Sarkar, S. K. (2008). Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria. *Progress in Electromagnetics Research*, *5*, 207-223.
5. Hossain, M. S., & Islam, M. A. (2017, February). Estimation of rain attenuation at EHF bands for earth-to-satellite links in Bangladesh. In *2017 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 589-593). IEEE.
6. Kalu, C., Ozuomba, S. & Jonathan, O. A. (2015). Rain rate trend-line estimation models and web application for the global ITU rain zones. *European Journal of Engineering and Technology, 3 (9)*, 14-29
7. Ononiwu, G., Ozuomba, S., & Kalu, C. (2015). Determination of the dominant fading and the effective fading for the rain zones in the ITU-R P. 838-3 recommendation. *European Journal of Mathematics and Computer Science Vol*, *2*(2).
8. Pinto-Mangones, A. D., Pérez-García, N. A., Torres-Tovio, J. M., Ramírez, E. J., Castaño-Rivera, S. O., Velez-Zapata, J., ... & Rujano-Molina, L. M. (2019). Rainfall rate and rain attenuation contour maps for preliminary “Simon Bolivar” satellite links planning in Venezuela. *Dyna*, *86*(209), 30-39.
9. Oloyede Adams Opeyemi, Ozuomba Simeon, Constance Kalu (2017) Shibuya Method for Computing Ten Knife Edge Diffraction Loss. Software Engineering 2017; 5(2): 38-43
10. Njoku Chukwudi Aloziem, Ozuomba Simeon, Afolayan J. Jimoh (2017) Tuning and Cross Validation of Blomquist-Ladell Model for Pathloss Prediction in the GSM 900 Mhz Frequency Band , *International Journal of Theoretical and Applied Mathematics*, *Journal*: Environmental and Energy Economics
11. Ozuomba, Simeon, Constance Kalu, and Akaninyene B. Obot. (2016) "Comparative Analysis of the ITU Multipath Fade Depth Models for Microwave Link Design in the C, Ku, and Ka-Bands." *Mathematical and Software Engineering* 2.1 (2016): 1-8.
12. Ozuomba, S., Enyenihi, J., & Rosemary, N. C. (2018). Characterisation of

Propagation Loss for a 3G Cellular Network in a Crowded Market Area Using CCIR Model. *Review of Computer Engineering Research*, *5*(2), 49-56.

13. Akaninyene B. Obot , Ozuomba Simeon and Afolanya J. Jimoh (2011); "*Comparative Analysis Of Pathloss Prediction Models For Urban Macrocellular" Nigerian Journal of Technology (NIJOTECH)* Vol. 30, No. 3 , October 2011 , PP 50 – 59
14. Akaninyene B. Obot , Ozuomba Simeon and Kingsley M. Udofia (2011); *"Determination Of Mobile Radio Link Parameters Using The Path Loss Models"* NSE Technical Transactions , A Technical Journal of The Nigerian Society Of Engineers, Vol. 46, No. 2 , April - June 2011 , PP 56 – 66.
15. Ozuomba, S., Johnson, E. H., & Udoiwod, E. N. (2018). Application of Weissberger Model for Characterizing the Propagation Loss in a Gliricidia sepium Arboretum. Universal Journal of Communications and Network 6(2): 18-23, 2018
16. Johnson, E. H., Ozuomba, S., & Asuquo, I. O. (2019). Determination of Wireless Communication Links Optimal Transmission Range Using Improved Bisection Algorithm. Universal Journal of Communications and Network 7(1): 9-20, 2019
17. Kalu, C. (2019). Development and Performance Analysis of Bisection Method-Based Optimal Path Length Algorithm for Terrestrial Microwave Link. *Review of Computer Engineering Research*, *6*(1), 1-11.
18. Ozuomba, Simeon (2019) SEEDED BISECTION NUMERICAL ITERATION BASED ON SINGLE TO DUAL INITIAL ROOT VALUES MECHANISM, Science and Technology Publishing (SCI & TECH) Vol. xx Issue xx, xxxx - 2019
19. Ozuomba, Simeon (2019) DEVELOPMENT OF SEEDED BISECTION ITERATION METHOD USING PERTURBATION-BASED MECHANISM, Journal of Multidisciplinary Engineering Science Studies (JMESS) Vol. xx Issue xx, xxxx – 2019
20. Ozuomba, Simeon (2019) DEVELOPMENT OF SINGLE TO DUAL INITIAL ROOT VALUES MECHANISM SUITABLE FOR BISECTION AND REGULAR FALSI ITERATION METHODS, International Multilingual Journal of Science and Technology (IMJST) Vol. x Issue x, xxxx- 2019
21. Obiyemi, O. O., Ibiyemi, T. S., & Akande, S. O. (2014). Rainfall variability and impact on Communication Infrastructure in Nigeria. *Journal of Telecommunications*, *25*(1).
22. Chebil, J., & Rahman, T. A. (1999). Development of 1 min rain rate contour maps for microwave applications in Malaysian Peninsula. *Electronics Letters*, *35*(20), 1772-1774.
23. Joseph, I., & Konyeha, C. C. (2013). Urban area path loss propagation prediction and optimisation using hata model at 800mhz. *IOSR Journal of Applied Physics (IOSR-JAP)*, *3*(4), 8-18.
24. Nisirat, M. A., Ismail, M., Nissirat, L. A., & Alkhawaldeh, S. A. (2011). A terrain roughness correction factor for hata path loss model at 900 MHz. *Progress In Electromagnetics Research*, *22*, 11-22.
25. Nadir, Z., & Ahmad, M. I. (2010, March). Pathloss determination using Okumura-Hata model and cubic regression for missing data for Oman. In *Proceedings of the International MultiConference of Engineers and Computer Scientists* (Vol. 2, pp. 17-19).
26. Singh, Y. (2012). Comparison of okumura, hata and cost-231 models on the basis of path loss and signal strength. *International journal of computer applications*, *59*(11).