International Multilingual Journal of Science and Technology (IMJST)
ISSN: 2528-9810
Vol. 5 Issue 1, January - 2020

COMPARISON OF THE OPTIMAL TRANSMISSION RANGE OF MICROWAVE COMMUNICATION LINKS FOR RAINFALL DATA WITH DIFFERENT PERCENTAGE OF EXCEEDANCE TIME

Akaninyene B. Obot
Department of Electrical/Electronic and Computer Engineering, University of Uyo, AkwaIbom State, Nigeria.
akaninyeneobot@uniuyo.edu.ng

Abstract— **In this paper, comparison of the optimal transmission range of microwave communication links for rainfall data set with different percentage of exceedance times is presented. In order to determine the effective transmission range, numerical iteration approach is employed. A flowchart for the iteration method was provided along with the key analytical models pertaining to the effective propagation loss computation. Three different cities in Nigeria were selected as case study and four different percentage of exceedance times (0.0001%, 0.01%, 0.1% and 1.0%) were selected. Specifically, the available rain volume data in mm per year was converted to rainfall rate of one minute integration time at 0.0001%, 0.01%, 0.1% and 1.0% . The different rainfall data was then used with free space path loss to determine the effective transmission range and other salient communication link parameters. The entire simulation was implemented in Matlab software. The simulation results for the city of Kano show that the optimal path length at rain rate, $R_{0.001}$ =187.4 mm/hr is the lowest with a value of 2.43175843 km with the highest rain fade depth of 28.26 dB while the optimal path length atrain rate , $R_{1.0}$ =12.7mm/hr is the lowest with a value of 20.34922205 km with the lowest rain fade depth of 9.81 dB . Essentially, the results showed that the higher the rain rate, the higher the rain fade depth will be and the lower the optimal path length will also be. Meanwhile, the operating rain rate increases as the percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%) decreases. It means that smaller percentage outage values present larger or higher rain rate values and hence higher rain fade depth and the corresponding lower optimal path length. Similar results are obtained for the city of Ibadan and for the city of Calabar. In all, among the three cities considered in this paper, the city of Calabar has the highest rain volume with the corresponding lowest set of optimal path lengths and highest set of rain fade depths for the various percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%). Specifically, for the city of Calabar, the optimal path length at $R_{0.001}$ = 313.5 mm/hr is 1.515642445 km and the rain fade depth is 32.36 dB while the optimal path length at $R_{1.0}$ =21.1 mm/hr is 14.50941872 km and the rain fade depth is 12.74 dB.**

Keywords — Transmission Range , Microwave Communication, Optimal Path Length, Communication Link, Rain Rate, Percentage Outage

I. INTRODUCTION

Across the globe, advancements in the wireless communication technologies have facilitated the wide adoption of wireless communications in diverse areas [1,2,3,4]. The growing demand poses running challenges as users demand more bandwidth and better Quality of Service (QoS). Accordingly, researchers and wireless network service providers and constantly seeking ways to expend their carrying capacity and at the same time meet the required QoS . One of the issues that designers consider in the wireless communication link is the maximum transmission range. Among other things, the maximum path length is dependent on the path loss, rain fade depth or multipath fade depth and other link parameters [5,6,7,8,9,10]. However, recent studies have shown that the effective transmission range should also be considered [11,12,13,14,15,16,17]. The effective transmission range is the path length at which the link budget computed fade margin is equal to the maximum fade depth available in the link at the required QoS.

In this paper, the study considers the effect of rain rate at different percentage of exceedance times. Specifically, the available rain volume data in mm per year was converted to rainfall rate of one minute integration time at 0.0001%, 0.01%, 0.1% and 1.0% . The different rainfall data was then used with free space path loss to determine the effective transmission range and other salient communication link parameters.

In order to determine the effective transmission range, numerical iteration approach is employed. A flowchart for the iteration method was provided along with the key analytical models pertaining to the effective propagation loss computation. Three different cities in Nigeria were selected as case study and four different percentage of exceedance times (0.0001%, 0.01%, 0.1% and 1.0%) were selected. The entire simulation was implemented in Matlab software.

II. METHODOLOGY

A. Rain Data

The rainfall data (Table 1) of two cities in the South-West region of Nigeria was used for the study. Particularly, data on the average annual rainfall in mm for Ibadan and Saki are presented in Table 1. The available rain volume data in mm per year was converted to rainfall rate of one minute integration time at 0.0001%, 0.01%, 0.1% and 1.0% using the following mathematical expressions [18, 19];

$$R_{0.001} = 21.338M^{0.3372} \quad (1)$$

$$R_{0.01} = 4.866M^{0.431} \quad (2)$$

$$R_{0.1} = 0.627M^{0.6} \quad (3)$$

$$R_{1.0} = 1.496M^{0.332} \quad (4)$$

where M is the accumulated average annual rain volume in mm and $R_{0.001}$, $R_{0.01}$, $R_{0.1}$ and $R_{1.0}$ are the one-minute integration time rain rates at 0.001%, 0.01%, 0.1% and 1.0% exceedances respectively. The annual rainfall volume and the computed rainfall rate for the various percentage of time exceeded are shown in Table 2.

Table 1 The rain data for the study area

S/ N	Station	Longitude (degrees)	Latitude (degrees)	Annual Mean Accumulated Rain (mm)
1	Kano	8.20	12.05	629.0
2	Ibadan	3.90	7.43	1397.1
3	Calabar	8.35	4.97	2891.8

(Source: [18])

Table 2 The annual rainfall volume and the rainfall rate for the various percentage of time exceeded

S/N	Station	Annual Mean Accumulated Rain (mm)	R0.00 1	R0.01	R0.1	R1.0
1	Kano	629.0	187.4	78.2	30.0	12.7
2	Ibadan	1397.1	245.3	110.3	48.4	16.6
3	Calabar	2891.8	313.5	151.0	74.8	21.1

B. Rain Fade Depth Computation

According to ITU-R (2005a) recommendations, for frequencies under 40 GHz and path lengths shorter than 60 km, the specific attenuation originating from rainfall is defined as $\gamma_{R_{po}}$ in dB/km and modelled using the power-law relationship as follows:

$$\gamma_{R_{po}} = k(R_{po})^{\alpha} \quad (5)$$

where R_{po} is the rainfall rate in mm/h exceeded for po% of an average year (or stated another way, R_{po} is the rainfall rate in mm/h for a particular link percentage outage, po). k and α are frequency dependent.

In ITU-R recommendations, specific attenuation originating from rainfall is defined separately for horizontal and vertical polarization [20, 21, 22, 23]. For the horizontal polarization and the vertical polarization;

$$\left.\begin{aligned} \langle\gamma_{R_{po}}\rangle_h &= K_h(R_{po})^{\alpha_h} \text{ in dB/km} \\ \langle\gamma_{R_{po}}\rangle_v &= K_v(R_{po})^{\alpha_v} \text{in dB/km} \end{aligned}\right\} \quad (6)$$

where k_h, α_h are frequency dependent coefficients for horizontal polarization. They are given in [20, 21, 22, 23] ; k_v, α_v are frequency dependent coefficients for vertical polarization. They are given in [20, 21, 22, 23] ; $\langle\gamma_{R_{po}}\rangle_h$ is the rain attenuation per kilometer for horizontal polarization; $\langle\gamma_{R_{po}}\rangle_v$ is the rain attenuation per kilometer for horizontal polarization; po is the Percentage outage time (or Percentage unavailability time) of the link; and pa is the Percentage availability time of the link.

$$po = (100\% - pa) \quad (7)$$

Rain fade depth, A_R (dB) is the product of specific rain attenuation, $\gamma_{R_{po}}$ in dB/km and the propagation path length, d (km) between the transmitter and the receiver.

$$A_R = (\gamma_{R_{po}})\, d \text{ (dB)} \quad (8)$$

In respect of ITU-R recommendations, the following terms can be defined [20, 21, 22, 23] :

$A_{R(h)}$ is the rain fade depth (attenuation) for horizontal polarization; $A_{R(v)}$ is the rain fade depth (attenuation) for vertical polarization; A_{Rain} is the operating rain fade depth (attenuation) considering both horizontal and vertical polarization; and d is the propagation path length or distance (in km) between the transmitter and the receiver.

Then;

$$\left.\begin{aligned} A_{R(h)} &= (\langle\gamma_{R_{po}}\rangle_h)\, d = (K_h(R_{po})^{\alpha_h})d \\ A_{R(v)} &= (\langle\gamma_{R_{po}}\rangle_v)\, d = (K_v(R_{po})^{\alpha_v})d \end{aligned}\right\} \quad (9)$$

$$A_{Rain} = \max\left((K_v(R_{po})^{\alpha_v}) * (K_h(R_{po})^{\alpha_h}) * d\right) = \max(A_{R(h)}, A_{R(v)})d \quad (10)$$

C. Microwave Communication Link Path Length Based On Free Space Path Loss Model

The potential maximum path length of a wireless communication link based on **Free Space Path Loss** (FSPL) can be found using the link budget equation;

$$P_R = P_T + (G_T + G_R) - LP_{FSPL(dB)} \quad (2)$$

where;

P_R = Received Signal Power (dBm)

P_T = Transmitter Power Output (dBm)

G_T = Transmitter Antenna Gain (dBi)

G_R = Receiver Antenna Gain (dBi)

$LP_{FSPL(dB)}$ = Free Space Path Loss (dB).

Hence, the path loss due to FSPL is given as;

$$LP_{FSPL(dB)} = P_T + G_T + G_R - P_R = 32.4 + 20\log(f*1000) + 20\log(d) \quad (3)$$

Therefore, with respect to the FSPL, the effective path length (d_{eFSPL}) is given as:

$$d_{eFSPL} = 10^{\left(\frac{(P_T + G_T + G_R - fm_S - P_S) - 32.4 - 20\log(f*1000)}{20}\right)} \quad (4)$$

With respect to d_{eFSPL}, the effective Free Space Path Loss, $\left(LP_{FSPL(dB)_e}\right)$ is given as:

$$LP_{FSPL(dB)_e} = 32.4 + 20\log(f*1000) + 20\log(d_{eFSPL}) \quad (5)$$

Effective Received Power (P_{ReFSPL}) is given as:

$$P_{ReFSPL} = P_T + G_T + G_R - LP_{FSPL(dB)_e} \quad (6)$$

Effective Fade Margin (fm_{eFSPL}) is given as:

$$fm_{eFSPL} = (\mathrm{P_T} + \mathrm{G_T} + \mathrm{G_R}) - (32.4 + 20\log(\mathrm{f} * 1000) + 20\log(d_{eFSPL})) - P_S \quad (7)$$

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

For 10 GHz microwave frequencies and above rain fading is the dominant fade mechanism. The rain fade depth (fd_{meFSPL}) at a path length (d_{eFSPL}) is given as;

$$fd_{meFSPL} = \max\left(\left(\mathrm{K_v}(\mathrm{R_{po}})^{\alpha_v}\right) * d_{eFSPL}, \left(\mathrm{K_h}(\mathrm{R_{po}})^{\alpha_h}\right) * d_{eFSPL}\right) \quad (8)$$

where:

k_h, α_h are frequency dependent coefficients for horizontal polarization. They are given in [20, 21, 22, 23] ;

kv, $\alpha_{,v}$ are frequency dependent coefficients for vertical polarization. They are given in [20, 21, 22, 23] ;

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

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

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

The optimal path length with path loss based on free space path loss model is the value of d_{eFSPL} and which $fm_{eFSPL} = fd_{meFSPL}$.

The flowchart used for the computation of the optimal path length for each rainfall rate for the various percentage of time exceeded is given in Figure 1.

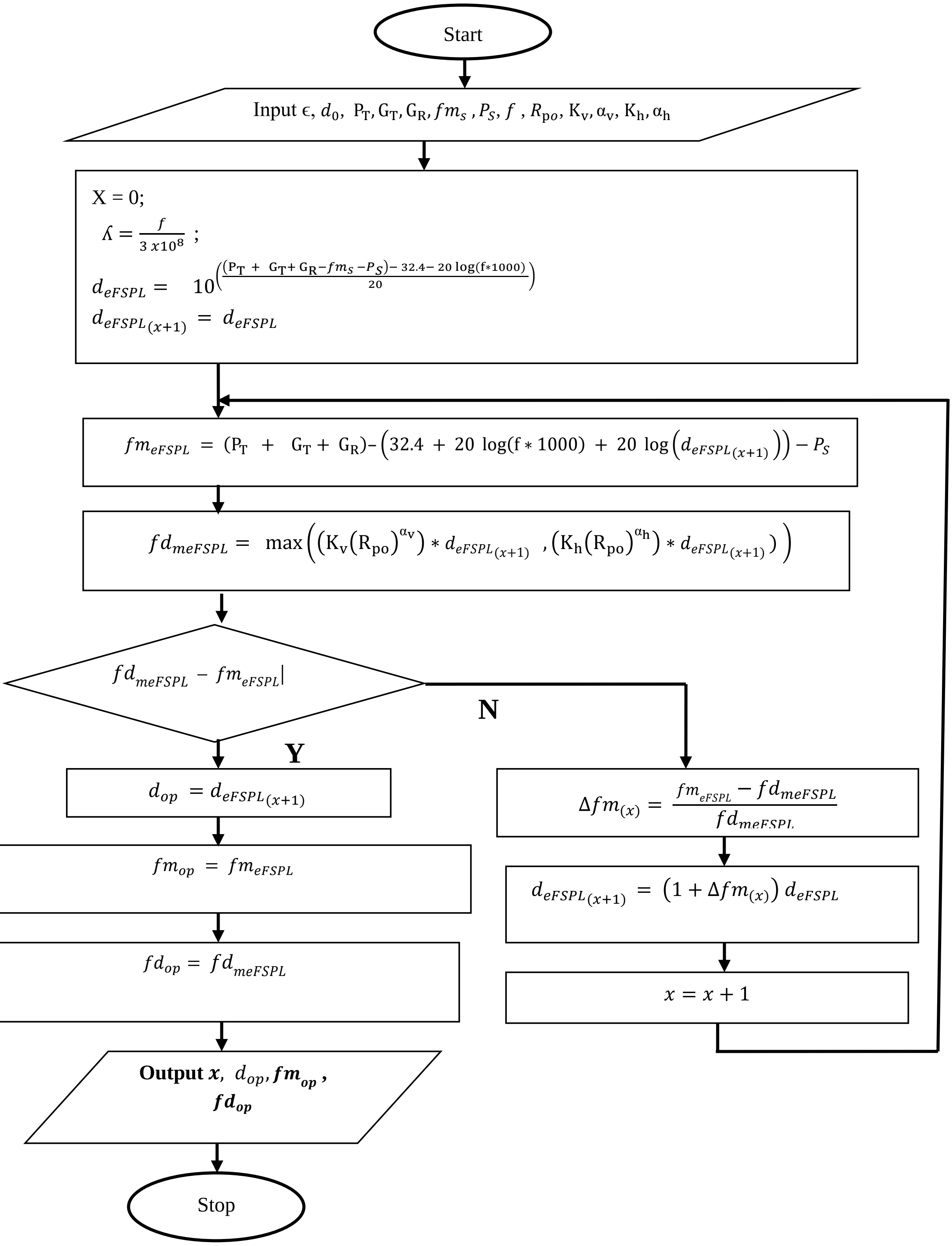

Figure 1. The flowchart used for the computation of the optimal path length for each rainfall rate for the various percentage of time exceeded

III. RESULTS AND DISCUSSION

A Matlab program was written for the flowchart of Figure 1 and the Matlab program was used to iteratively compute the optimal path length based on the communication link parameters presented in Table 3 and the rain data presented in Table 2.

The simulation results for the city of Kano is presented in Table 4 . The results in Table 4 and Figure 2 show that the effective transmission range or optimal path length at $R_{0.001} = 187.4$ mm/hr is the lowest with a value of 2.43175843 km and the highest rain fade depth of 28.26 dB while the optimal path length at $R_{1.0}$=12.7mm/hr is the lowest with a value of 20.34922205 km and the lowest rain fade depth of 9.81 dB . Essentially, the results showed that the higher the rain rate, the higher the rain fade depth will be and the lower the optimal path length will also be. Meanwhile, the operating rain rate increases as the percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%) decreases. It means that smaller percentage outage values present larger or higher rain rate values and hence higher rain fade depth and the corresponding lower optimal path length.

Similar results are obtained for the city of Ibadan (in Table 5 and Figure 3) and for the city of Calabar (in Table 6 and Figure 4). In Table 5 and Figure 3 for the city of Ibadan, the optimal path length at $R_{0.001} = 245.3$ mm/hr is the lowest with a value of 1.902215729 km and the highest rain fade depth of 30.39 dB while the optimal path length at $R_{1.0}$=16.6 mm/hr is the lowest with a value of 17.10592516 km and the lowest rain fade depth of 11.31dB. In Table 6 and Figure 4 for the city of Calabar, the optimal path length at $R_{0.001} = 313.5$ mm/hr is the lowest with a value of 1.515642445 km and the highest rain fade depth of 32.36 dB while the optimal path length at $R_{1.0}$=21.1 mm/hr is the lowest with a value of 14.50941872 km and the lowest rain fade depth of 12.74 dB.

In all, among the three cities considered in this paper, the city of Calabar has the highest rain volume with the corresponding lowest set of optimal path lengths and highest set of rain fade depths for the various percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%).

Table 3 The simulation input parameters for the communication link

S/N	Parameter Name and Unit	Parameter Value	S/N	Parameter Name and Unit	Parameter Value
1	f (MHz)	12000	8	kh	0.02386
2	Transmitter power, P_T(dB)	15	9	ah	1.1825
3	Transmitter antenna Gain, G_T(dB)	26	10	kv	0.02455
4	Receiver antenna gain, G_R(dB)	26	11	av	1.1216
5	Receiver sensitivity, P_s (dB)	-83	12	Percentage Availability, Pa (%)	99.999
6	Fade Margin (dB)	14	13	Percentage Outage, Po (%)	0.001
7	Location Name	Ibadan	14	Rain Rate (mm/hr)	244.3147

Table 4 The simulation results for the link located in the city of Kano

S/N	Station	Rain Rate (mm.hr)	Percentage Outage, Po (%)	Transmission Range (km)	Propagation Loss by FSPL Model (dB)	Effective Rain Fade Depth (dB)
1	Kano	$R_{0.001}$ =187.4	0.001	2.43175843	121.7420335	28.26
2	Kano	$R_{0.01}$ = 78.2	0.01	5.227356046	128.3892666	21.61
3	Kano	$R_{0.1}$= 30	0.1	11.23720689	135.0367925	14.96
4	Kano	$R_{1.0}$=12.7	1.0	20.34922205	140.1945811	9.81

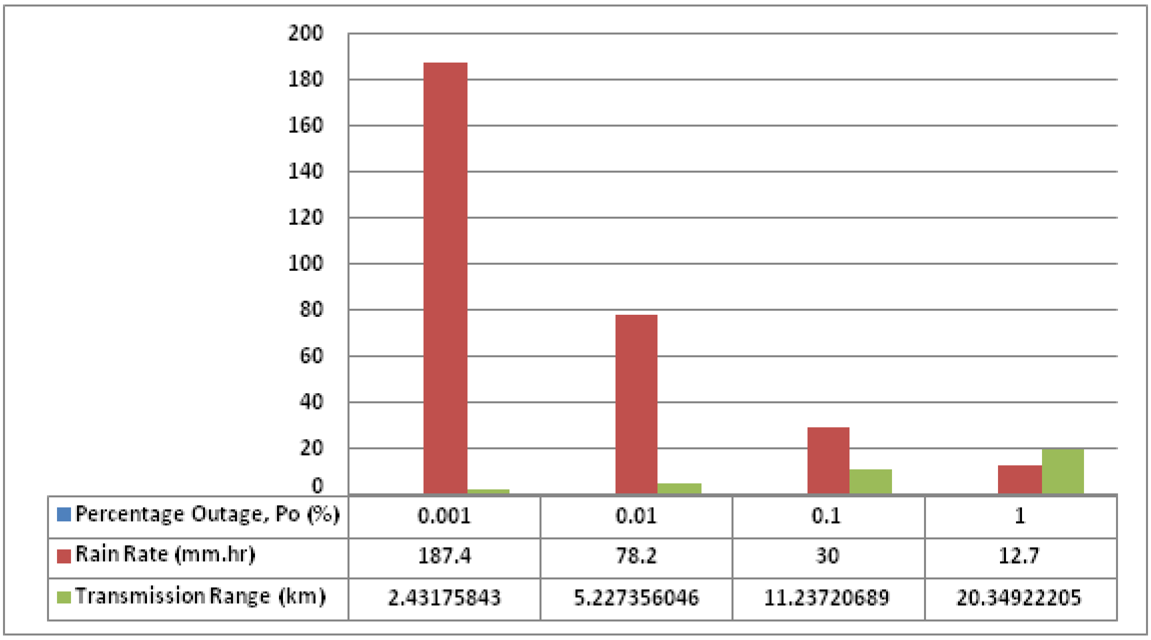

Figure 2 Comparison of the rain rate and transmission range for the various percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%) for the city of Kano

Table 5 The simulation results for the link located in the city of Ibadan

S/N	Station	Rain Rate (mm.hr)	Percentage Outage, Po (%)	Transmission Range (km)	Propagation Loss by FSPL Model (dB)	Effective Rain Fade Depth (dB)
1	**Ibadan**	$R_{0.001}$ =245.3	0.001	1.902215729	119.6088203	30.39
2	**Ibadan**	$R_{0.01}$ = 110.3	0.01	3.892924879	125.8291454	24.17
3	**Ibadan**	$R_{0.1}$= 48.4	0.1	7.756512993	131.8169554	18.18
4	**Ibadan**	$R_{1.0}$=16.6	1.0	17.10592516	138.6865563	11.31

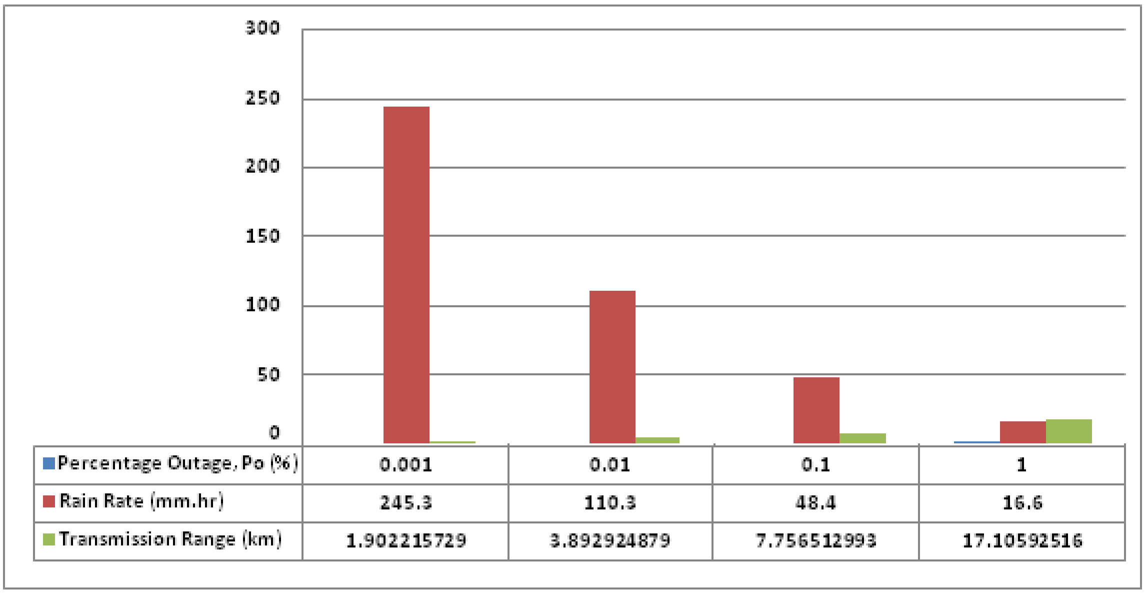

Figure 3 Comparison of the rain rate and transmission range for the various percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%) for the city of Ibadan

Table 6 The simulation results for the link located in the city of Calabar

S/N	Station	Rain Rate (mm.hr)	Percentage Outage, Po (%)	Transmission Range (km)	Propagation Loss by FSPL Model (dB)	Effective Rain Fade Depth (dB)
1	**Calabar**	$R_{0.001}$ =313.5	0.001	1.515642445	117.6355601	32.36
2	**Calabar**	$R_{0.01}$ = 151	0.001	2.952157186	123.4264145	26.57
3	**Calabar**	$R_{0.1}$= 74.8	0.001	5.426630819	128.7142305	21.29
4	**Calabar**	$R_{1.0}$=21.1	0.001	14.50941872	137.2566252	12.74

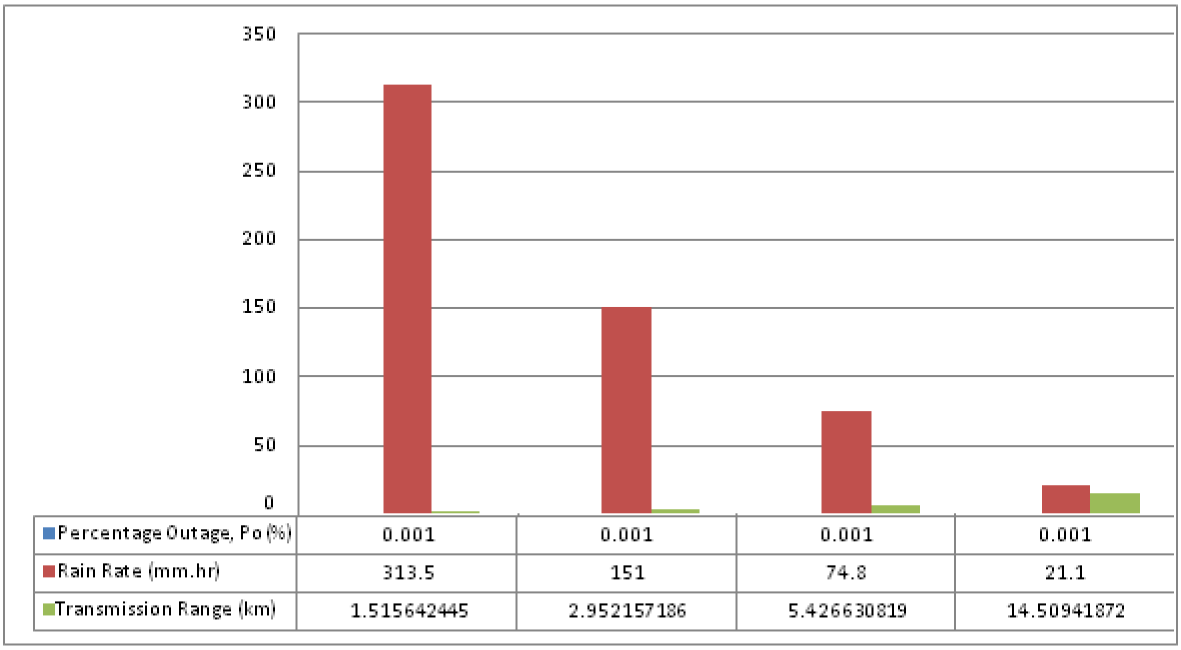

Figure 4 Comparison of the rain rate and transmission range for the various percentage outage values (namely, 0.001 %, 0.01%, 0.1 % and 1.0%) for the city of Calabar

IV. CONCLUSION

Analytical expressions and numerical iteration flowchart for computing the optimal path length of wireless communication link in the Ku-band is presented. The computations were performed in Matlab software using rain data for three different cities in Nigeria. The three cities have different annual mean rainfall volume. The optimal path length and other pertinent link parameters were computed for the rain rates at various percentage outage values (of, 0.001 %, 0.01%, 0.1 % and 1.0%). The results showed that the smaller the percentage outage value , the higher the rain rate. Furthermore, higher rain rate gives higher rain fade depth and lower optimal path length . In addition, The city of Calabar with the highest annual mean rain volme has the highest rain rate data for the various percentage outage values (of, 0.001 %, 0.01%, 0.1 % and 1.0%). Hence, communication links in the city of Calabar will experience the highest rain fade depth and will require more network resource to ensure network coverage of a given wide area when compared to the resources that will be required for the case of Kano and Ibadan.

REFERENCES

1. Yang, P., Xiao, Y., Xiao, M., & Li, S. (2019). 6G wireless communications: Vision and potential techniques. *IEEE Network*, *33*(4), 70-75.
2. Niyato, D., Kim, D. I., Maso, M., & Han, Z. (2017). Wireless powered communication networks: Research directions and technological approaches. *IEEE Wireless Communications*, *24*(6), 88-97.
3. Raychaudhuri, D., & Mandayam, N. B. (2012). Frontiers of wireless and mobile communications. *Proceedings of the IEEE*, *100*(4), 824-840.
4. Miller, L. E. (2005). Wireless Technologies and the SAFECOM SoR for Public Safety Communications. *National Institute of Standards and Technology, Month Unknown*, 1-68.
5. Ononiwu, G., Ozuomba, Simeon , & 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).

6. 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
7. 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
8. 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.
9. Ononiwu, G., Ozuomba, Simeon., & 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).
10. Ozuomba, Simeon, 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
11. 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.
12. 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.
13. Ozuomba, Simeon (2019) ANALYSIS OF EFFECTIVE TRANSMISSION RANGE BASED ON HATA MODEL FOR WIRELESS SENSOR NETWORKS IN THE C-BAND AND KU-BAND, Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. xx Issue xx, xxxx – 2019
14. Nnadi, N. C., Nnadi, C. C., & Nnadi, I. C. (2017). Computation of diffraction parameter as a function of line of site percentage clearance. *Mathematical and Software Engineering*, *3*(1), 149-155.
15. Ezenugu, I. A. Link Budget Analysis For Non-Line-Of-Sight Microwave Communication Link With Single Knife Edge Diffraction Obstruction.
16. Ozuomba, Simeon (2019) EVALUATION OF OPTIMAL TRANSMISSION RANGE OF WIRELESS SIGNAL ON DIFFERENT TERRAINS BASED ON ERICSSON PATH LOSS MODEL , Science and Technology Publishing (SCI & TECH)
17. Kalu, C., Ozuomba, Simeon & 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
18. Semire, F. A., Adekunle, A., & Abolade, R. O. (2019). A Study on Rain Rate Prediction of Southwestern Nigeria. *Physical Science International Journal*, 1-12.
19. Semire, F. A., & Rosmiwati, M. M. (2011). Development of rain rate prediction model for Nigeria. *Canadian Journal of Pure & Applied Sciences*, *5*(3), 1721-1728.
20. Series, R. P. (2015). Propagation data and prediction methods required for the design of terrestrial line-of-sight systems. *Recommendation ITU-R*, 530-11.
21. Shrestha, S., & Choi, D. Y. (2019). Rain attenuation study over an 18 GHz terrestrial microwave link in South Korea. *International Journal of Antennas and Propagation*, *2019*.
22. International Telecommunication Union Radio communication, ITU-R. Characteristics of Precipitation for Propagation Modelling, Recommendation ITU-R P. 2012;837-6
23. Mandeep, J. S. (2009). Slant path rain attenuation comparison of prediction models for satellite applications in Malaysia. *Journal of Geophysical Research: Atmospheres*, *114*(D17).