Analysis of degree of urbanization impact on LoRa-based wireless sensor communication link

Kufre M. Udofia
Department of Electrical/Electronic and Computer Engineering,
University of Uyo, Nigeria
kmudofia@uniuyo.edu.ng

***Abstract*— In this paper, Analysis of degree of urbanization impact on LoRa-based wireless sensor communication link is presented. The CCIR path loss prediction model use a degree of urbanization parameter, (denoted as E) to differentiate the path loss that can be experienced in different environments, from open space with minimal buildings or obstructions to urban area with so many buildings and obstructions. The mathematical expressions for the CCIR model and the link budget analysis of the wireless link are presented. Sample numerical computations were conducted with transmitter power of 10 dBm and path length values ranging from 1.6 km to 7.1 km, as well as the following parameters : PB=3% and E =18.08; PB = 8% and E =7.43 ; PB = 16% and E = 0. Notably, the results show that the CCIR estimated pathloss increases with increase in the PB and hence increase in the degree of urbanization, E. Specifically, the least path loss values are obtained when PB =3 % which is for the rural area while the highest values of path loss are obtained when PB =16 % which is for the urban area. the received signal strength decreases with increase in the PB and hence the received signal strength decreases with increase in the degree of urbanization, E.In all, the results show that for a given path length, the path loss increases with increase in degree of urbanization, the received signal strength decreases with increase in degree of urbanization, and also the decreases with increase in degree of urbanization. Also, for a given path length, the link margin increases with increase in spreading factor.**

Keywords*— *Link Margin , LoRa Transceiver , Smart Systems, Internet Of Things (IoT), Sensor Node, Receiver Sensitivity, CCIR Model

1. Introduction

Generally, the wired and fiber optic network technologies are known to afford high bandwidth, however, the wireless communication technologies has continued to dominate in many application areas [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15, 16]. Notabley, GSM and satellite communications, as well as Internet of Things and wireless sensor networks are some applications that rely heavily on wireless communication technologies [16,17,18,19,20, 21,22, 23,24, 25,26, 27,28, 29]. Moreover, Long Range (LoRa) transceiver technologies have become one of the most popular communication technologies employed in wireless sensor networks [31,32,33,34,35,36,37,38,39,40]. Due to its low energy consumption and long range communication capability, it has been applied in terrestrial and also in direct earth to satellite wireless sensor communications [41,42,43,44]. In any case, designers of LoRa-based wireless sensor communication link must address some challenges that are mostly prevalent in wireless communication links. Particularly, path loss is one of the challenges that wireless communication link designers must determine and accommodate in their design in order to achieve and sustain their set quality of service [45,46,47,48]. Other related challenges are diffraction loss and also fading due to rain and multipath. While fade mechanisms may occur occasionally, path loss is inevitable and it is present by default. However, the exact amount of path loss experienced in a wireless link is significantly affected by the nature and distribution of obstructions in the signal propagation area.

Importantly, different mathematical models have been developed in different studies to estimate the path loss in different propagation environments. The CCIR model is among the empirical models that are used to estimate the path loss in different areas classified by the degree of urbanization [49,50,51]. The degree of urbanization is dependent on the percentage of the area that is covered by buildings. The model originators associated certain values of the degree of urbanization to urban area, to sub-urban area and to rural area. As such, this paper is set to determine the effect of the degree of urbanization on the LoRa-based wireless sensor communication link. Specifically, the study considered the link margin variations with different configurations of degree of urbanization and path length.

2. Methodology

The CCIR path loss prediction model use a degree of urbanization parameter, (denoted as E) to differentiate the path loss that can be experienced in different environments, from open space with minimal buildings or obstructions to urban area with so many buildings and obstructions. In the CCIR model, the path loss, $LP\ (dB)$is expressed as;

$$LP\ (dB) = A + B * \log_{10}(d) - E \qquad (1)$$

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \qquad (2)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \qquad (3)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \qquad (4)$$

$$\mathrm{E} = 30 - 25(\log_{10}(PB)) \qquad (5)$$

Where d is the path length given in km and f is signal frequency given in MHz within the range of 150 MHz≤ f≤ 1000MHz, h_b is the transmitter antenna height which is within the range of 30m $\leq h_b \leq$ 200m, h_m is the transmitter antenna height which is within the range of 1m≤ h_m≤ 10 m . The value of E is given in respect of PB that is a numerical representation of percentage of the area that is covered with buildings and obstructions. Typical values of PB are such that;

$$PB \begin{cases} \geq 16\ \%\ for\ urban\ area \\ = 8\ \%\ for\ sub-urban\ area \\ = 3\ \%\ for\ rural\ or\ open\ area \end{cases} \tag{6}$$

Now, LoRa transceiver sensitivity, S_{rsens} is expressed as;

$$S_r = -174 + 10\log_{10}(BW) + NF + SNR_{RQD} \tag{7}$$

Where the SNR_{RQD} is the required signal to noise ratio, NF is the noise figure and BW is the noise bandwidth. Also, when the transmitter and receiver antenna gains are assumed to be negligible, the receiver signal power, P_r can be determined using the link budget expression for the LoRa transceiver-based communication link given as;

$$P_r = P_t - LP\ (dB) \tag{8}$$

$$P_r = LM + S_{rsens} \tag{9}$$

$$P_t - LP\ (dB) = LM + S_{rsens} \tag{10}$$

$$LM = P_t - LP\ (dB) - S_{rsens} \tag{11}$$

Where LM is the link margin, P_t is the transmitter power and $LP\ (dB)$ is the path loss which in this paper is based on the CCIR model.

3. Results and discussions

A numerical example was conducted with transmitter power of 10 dBm and path length values ranging from 1.6 km to 7.1 km and the results of the CCIR pathloss, $LP\ (dB)$ for PB=3%, 8 % and 16 % are presented in Table 1 and Figure 1. Notably, the results show that the CCIR estimated pathloss increases with increase in the PB and hence increase in the degree of urbanization, E. The set of pathloss values obtained show that the least path loss values are obtained when PB =3 % which is for the rural area while the highest values of path loss are obtained when PB =16 % which is for the urban area.

Table 1 The results of the CCIR pathloss, $LP\ (dB)$ for PB=3%, 8 % and 16 %

d (km)	CCIR Path loss PB=3% and E =18.08	CCIR Path loss PB = 8% and E =7.43	CCIR Path loss PB = 16% and E =0
1.6	96	106.7	114.2
2.7	103.8	114.5	122
3.8	108.9	119.6	127.1
4.9	112.7	123.4	130.9
6	115.8	126.4	133.9
7.1	118.3	128.9	139.5

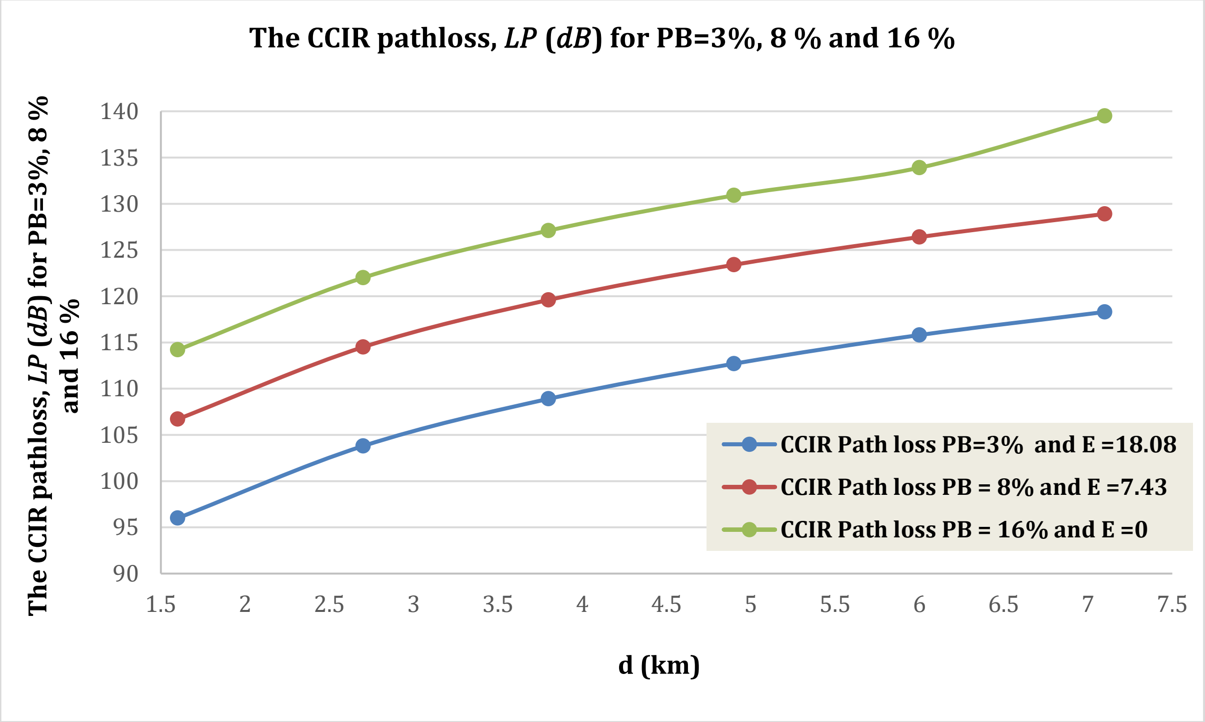

Figure 1 The scatter plot of the CCIR pathloss, $LP\ (dB)$ for PB=3%, 8 % and 16 %

Furthermore, received signal strength, Pr (dB) for PB=3%, 8 % and 16 % was computed based on the path loss results presented in Table 1 and Figure 1 and the received signal strength results are presented in Table 2 and Figure 2. The results show that the received signal strength decreases with increase in the PB and hence the received signal strength decreases with increase in the degree of urbanization, E. The strongest received signal strength values are obtained when PB =3 % which is for the rural area while the weakest received signal strength are obtained when PB =16 % which is for the urban area.

Table 2 The received signal strength, Pr (dB) for PB=3%, 8 % and 16 %

d (km)	The Received Signal Strength, Pr (dB) for PB=3% and E =18.08	The Received Signal Strength, Pr (dB) for PB = 8% and E =7.43	The Received Signal Strength, Pr (dB) for PB = 16% and E =0
1.6	-96.7	-96.7	-104.2
2.7	-104.5	-104.5	-112
3.8	-109.6	-109.6	-117.1
4.9	-113.4	-113.4	-120.9
6	-116.4	-116.4	-123.9
7.1	-118.9	-118.9	-129.5

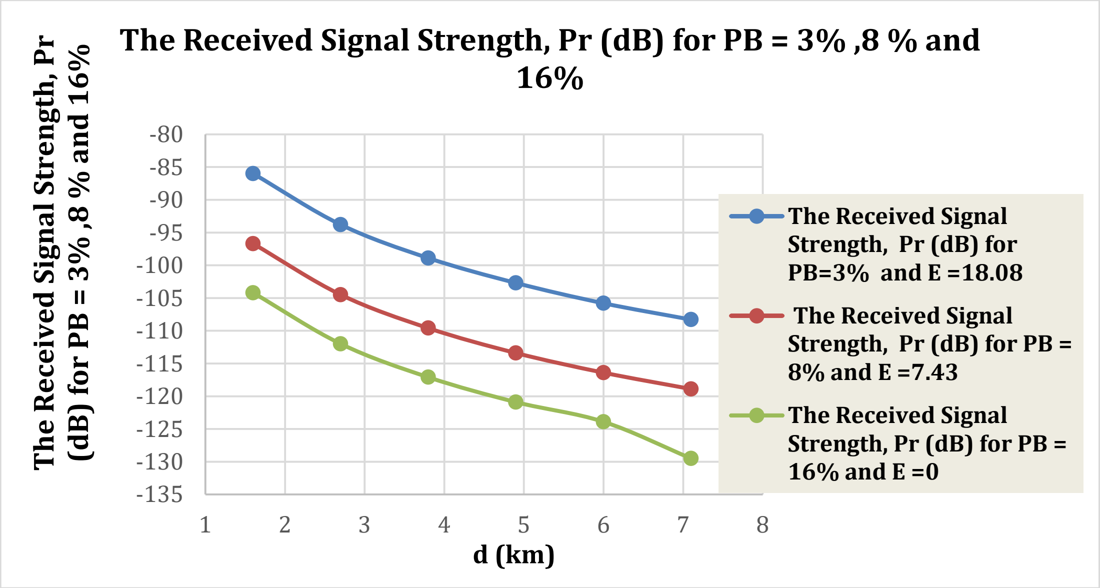

Figure 2 The scatter plot of the received signal strength, Pr (dB) for PB=3%, 8 % and 16 %

Also, the results of the link margin, LM (dB) for PB =3% and E =18.08 are presented in Table 3 and Figure 3. Similarly, the results of the link margin, LM (dB) for PB =3% and E =18.08 are presented in Table 4 and Figure 4 while the results of the link margin, LM (dB) for PB = 16% and E =0 are presented in Table 5 and Figure 5.

The results show that the link margin decreases with increase in the path length, d. On the other hand, the link margin increases with increase in the spreading factor, from SF =7 to SF =12. Hence, the link margin for the spreading factor of 12 is highest at all the values of the link path length.

The results of the link margin LM (dB) of SF = 7 for PB=3%, 8 % and 16 % are presented in table 6 and Figure 6. Again, the results show that the link margin is highest for the rural area with PB =3% and E =18.08 while the link margin is smallest for the urban area with PB = 16% and E =0.

Table 3 The results of the link margin, LM (dB) for PB =3% and E =18.08

The Link Margin, LM (dB) for PB =3% and E =18.08						
d (km)	SF = 7	SF = 8	SF = 9	SF = 10	SF = 11	SF = 12
1.6	40.5	43	45.5	48	50.5	53.5
2.7	32.7	35.2	37.7	40.2	42.7	45.7
3.8	27.6	30.1	32.6	35.1	37.6	40.6

4.9	23.8	26.3	28.8	31.3	33.8	36.8
6	20.7	23.2	25.7	28.2	30.7	33.7
7.1	18.2	20.7	23.2	25.7	28.2	31.2

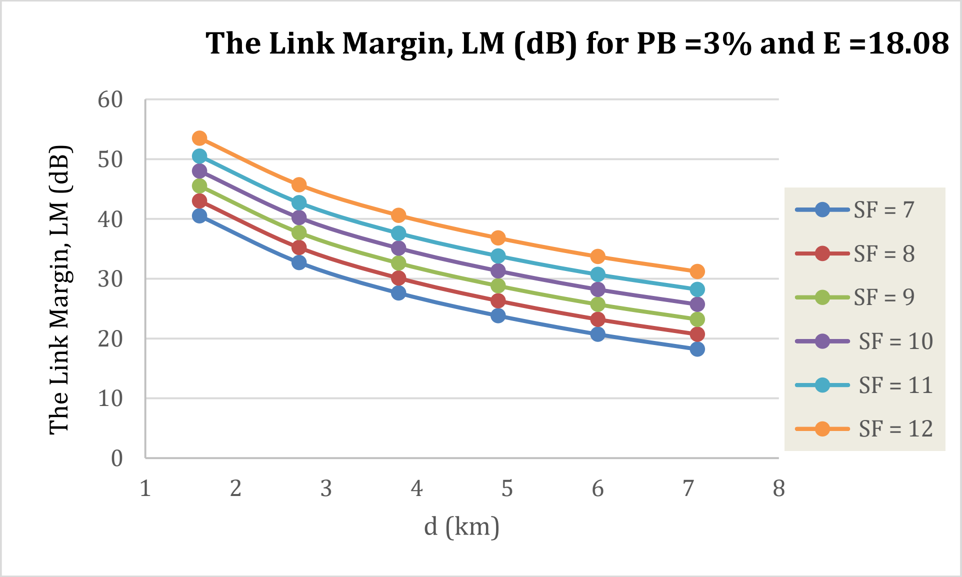

Figure 3 The scatter plot of the link margin, LM (dB) for PB =3% and E =18.08

Table 4 The results of the link margin, LM (dB) for PB = 8% and E =7.43

The Link Margin, LM (dB) for PB = 8% and E =7.43						
d (km)	SF = 7	SF = 8	SF = 9	SF = 10	SF = 11	SF = 12
1.6	29.8	32.3	34.8	37.3	39.8	42.8
2.7	22	24.5	27	29.5	32	35
3.8	16.9	19.4	21.9	24.4	26.9	29.9
4.9	13.1	15.6	18.1	20.6	23.1	26.1
6	10.1	12.6	15.1	17.6	20.1	23.1
7.1	7.6	10.1	12.6	15.1	17.6	20.6

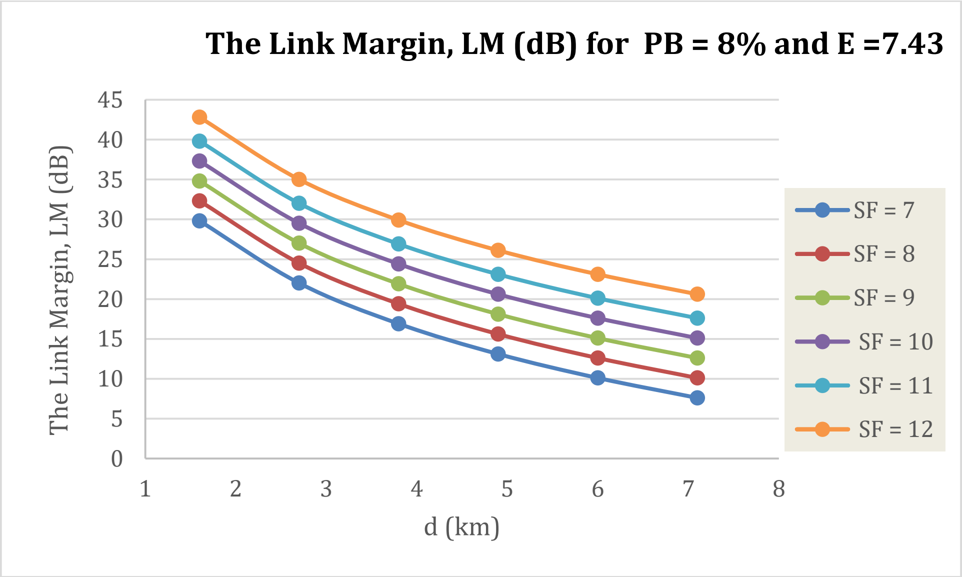

Figure 4 The scatter plot of the link margin, LM (dB) for PB = 8% and E =7.43

Table 5 The results of the link margin, LM (dB) for PB = 16% and E =0

The Link Margin, LM (dB) for PB = 16% and E =0						
d (km)	SF = 7	SF = 8	SF = 9	SF = 10	SF = 11	SF = 12
1.6	22.3	24.8	27.3	29.8	32.3	35.3
2.7	14.5	17	19.5	22	24.5	27.5
3.8	9.4	11.9	14.4	16.9	19.4	22.4
4.9	5.6	8.1	10.6	13.1	15.6	18.6
6	2.6	5.1	7.6	10.1	12.6	15.6
7.1	-3	-0.5	2	4.5	7	10

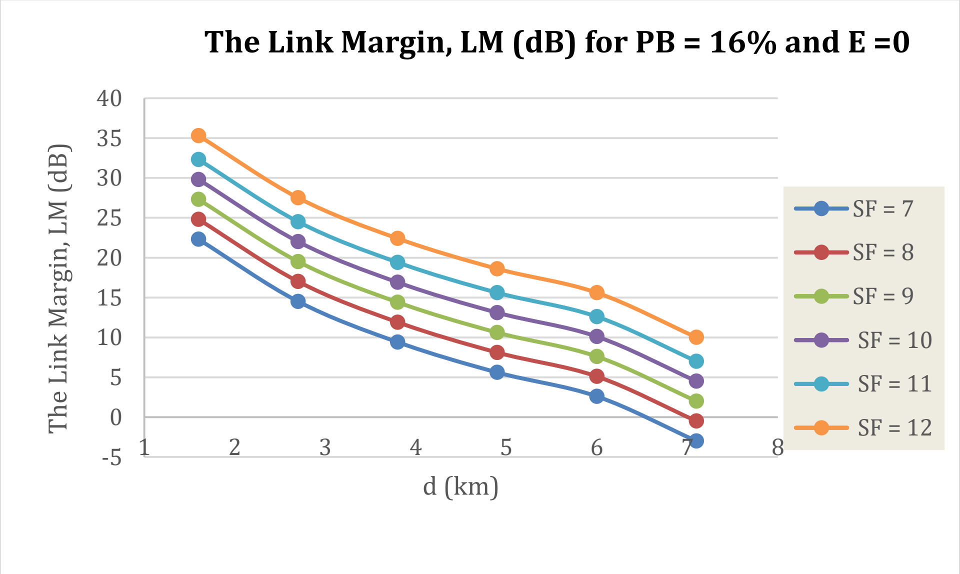

Figure 5 The scatter plot of the link margin, LM (dB) for PB = 16% and E =0

Table 6 The results of the link margin LM (dB) of SF = 7 for PB=3%, 8 % and 16 %

The Link Margin LM (dB) of SF = 7 for for PB=3%, 8 % and 16 %			
d (km)	SF = 7: The Link Margin, LM (dB) for PB =3% and E =18.08	SF = 7: The Link Margin, LM (dB) for PB = 8% and E =7.43	SF = 7: The Link Margin, LM (dB) for PB = 16% and E =0
1.6	40.5	29.8	22.3
2.7	32.7	22	14.5
3.8	27.6	16.9	9.4
4.9	23.8	13.1	5.6
6	20.7	10.1	2.6
7.1	18.2	7.6	-3

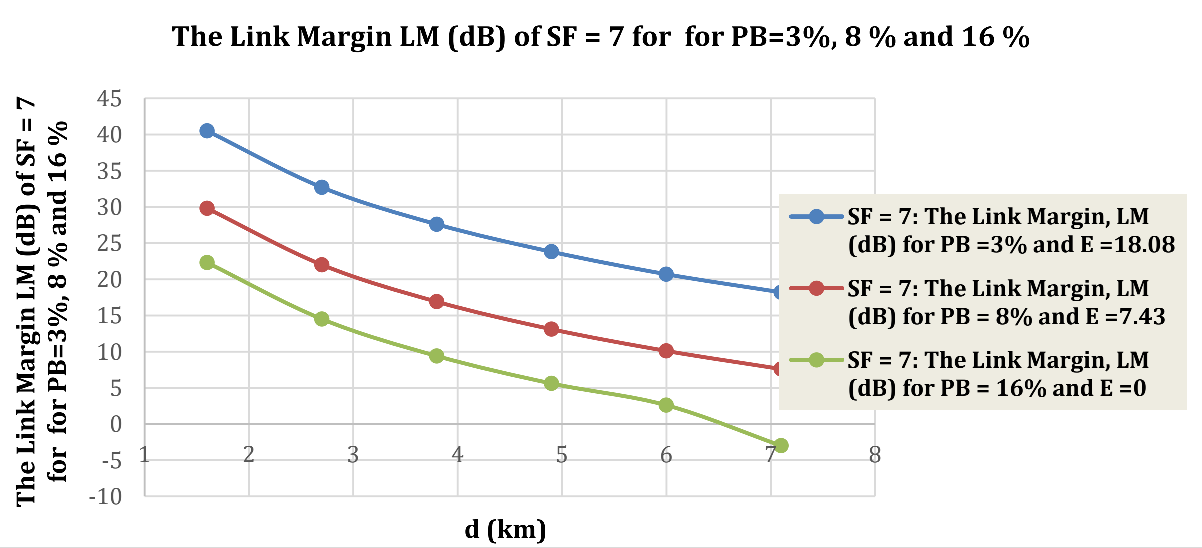

Figure 6 The scatter plot of the link margin, LM (dB) for PB=3%, 8 % and 16 %

4. Conclusion

The effect of the degree of urbanization on the LoRa wireless sensor network communication link is presented. The degree of urbanization is a parameter used in the CCIR path loss model to differentiate different wireless signal propagation environment. Notably, an urbanization degree computed with obstruction covered area of 3% is for rural area whereas the urbanization degree computed with obstruction covered area of greater or equal to 16% is for urban areas. The study considered the degree of urbanization of the path loss, the received signal strength and the link margin for LoRa-based sensor network.

The results show that for a given path length, the path loss increases with increase in degree of urbanization, the received signal strength decreases with increase in degree of urbanization, and also the decreases with increase in degree of urbanization. Also, for a given path length, the link margin increases with increase in spreading factor.

Reference

1. Kawanishi, T., Kanno, A., & Freire, H. S. (2018). Wired and wireless links to bridge networks: Seamlessly connecting radio and optical technologies for 5G networks. *IEEE Microwave Magazine*, *19*(3), 102-111.
2. Maier, M., Ghazisaidi, N., & Reisslein, M. (2009). The audacity of fiber-wireless (FiWi) networks. In *AccessNets: Third International Conference on Access Networks, AccessNets 2008, Las Vegas, NV, USA, October 15-17, 2008. Revised Papers 3* (pp. 16-35). Springer Berlin Heidelberg.
3. Ozuomba Simeon and Chukwudebe G. A.(2003) *An improved algorithm for channel capacity allocation in timer controlled token passing protocols, The Journal of Computer Science and its Applications (An international Journal of the Nigerian Computer Society (NCS)) Vol. 9, No. 1 , June 2003 , PP 116 124*
4. Pahlavan, K., & Krishnamurthy, P. (2009). *Networking fundamentals: Wide, local and personal area communications*. John Wiley & Sons.
5. Ozuomba Simeon and Chukwudebe G. A. (2004) *A new priority scheme for the asynchronous traffic in timer-controlled token passing protocols, The Journal of Computer Science and its Applications (An international Journal of the Nigerian Computer Society (NCS)) Vol. 10, No. 2 , December 2004 , PP 17 -25*
6. Ozuomba Simeon and Chukwudebe G. A.(2011) ; *"Performance Analysis Of Timely-Token Protocol With Variable Load Of Synchronous Traffic" NSE Technical Transactions , A Technical Journal of The Nigerian Society Of Engineers,* Vol. 46, No. 1 Jan – March 2011, PP 34 – 46.
7. Ozuomba, Simeon, Amaefule, C. O., & Afolayan, J. J. (2013). Optimal Guaranteed Services Timed Token (OGSTT) Media Access Control (Mac) Protocol For Networks That Support Hard Real-Time And Non Real-Time Traffic. *Nigerian Journal of Technology (NIJOTECH) 32*(3), 470-477
8. Kalu, C., Ozuomba, Simeon., & Anthony, U. M. (2015). STATIC-THRESHOLD-LIMITED BuST PROTOCOL. *European Journal of Mathematics and Computer Science Vol, 2(2).*
9. Simeon, Ozuomba. (2016). Evaluation Of Bit Error Rate Performance Of Multi-Level Differential Phase Shift Keying. Evaluation, 1(8). *International Multilingual Journal of Science and Technology (IMJST) Vol. 1 Issue 8, August – 2016*
10. Boucouvalas, A. C., Chatzimisios, P., Ghassemlooy, Z., Uysal, M., & Yiannopoulos, K. (2015). Standards for indoor optical wireless communications. *IEEE Communications Magazine*, *53*(3), 24-31.
11. Kalu C., Ozuomba S., and Mbocha C.C. (2013) Performance Analysis of Static- Threshold-Limited On-Demand Guaranteed Services Timed Token Media Access Control Protocol Under Non Uniform Heavy Load of Asynchronous Traffic. *NSE Technical Transactions, A Technical Journal of the Nigerian Society of Engineers*, Vol. 47, No. 3 July – Sept 2013,

12. Constance Kalu, Simeon Ozuomba and Umoren Mfonobong Anthony (2015) Performance Analysis of Fiber Distribution Data Interface Network Media Access Control Protocol Under-Uniform Heavy load of Asynchronous Traffic. European Journal of Basic and Applied Sciences. Vol 2 No. 4
13. Kalu, S. Ozuomba, G. N. Onoh (2011) ANALYSIS OF TIMELY-TOKEN PROTOCOL WITH NON-UNIFORM HEAVY LOAD OF ASYNCHRONOUS TRAFFIC. Electroscope Journal Vol. 5 No. 5 (2011)
14. Ozuomba Simeon , Chukwudebe G. A. and Akaninyene B. Obot (2011); *"Static-Threshold-Limited On-Demand Guaranteed Service For Asynchronous Traffic In Timely-Token Protocol " Nigerian Journal of Technology (NIJOTECH)* Vol. 30, No. 2 , June 2011 , PP 124 – 142
15. Kalu C. , Ozuomba Simeon, Onoh G.N. (2013) Dynamic Threshold limited timed token (DTLTT) Protocol *Nigerian Journal of Technology (NIJOTECH)* Vol. 32. No. 1. March 2013, pp. 266-272.
16. Constance Kalu, Simeon Ozuomba and Umoren Mfonobong Anthony (2015) Static-Threshold-Limited Bust Protocol, European Journal of Mathematics and Computer Science, Vol. 2 N0. 2
17. Uduak Idio Akpan, Constance Kalu, Simeon Ozuomba, Akaninyene Obot (2013). Development of improved scheme for minimising handoff failure due to poor signal quality. *International Journal of Engineering Research & Technology (IJERT), 2(10), 2764-2771*
18. Simeon, Ozuomba. (2016) "Development And Application Of Complementary Root-Based Seeded Secant Iteration For Determination Of Semi Major Axis Of Perturbed Orbit" *International Multilingual Journal of Science and Technology (IMJST) Vol. 1 Issue 2, July – 2016*
19. Simeon, Ozuomba. (2017). "Determination Of The Clear Sky Composite Carrier To Noise Ratio For Ku-Band Digital Video Satellite Link" *Science and Technology Publishing (SCI & TECH) Vol. 1 Issue 7, July – 2017*
20. Ogbonna Chima Otumdi , Ozuomba Simeon, Kalu Constance (2020). Clustering Of 2100 Mhz Cellular Network Devices With Som Algorithm Using Device Hardware Capacity And Rssi Parameters *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 2, February – 2020*
21. 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.
22. Akpan, Itoro J., Ozuomba Simeon, and Kalu Constance (2020). "Development Of A Guard Channel-Based Prioritized Handoff Scheme With Channel Borrowing Mechanism For Cellular Networks." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 2, February - 2020*
23. Simeon, Ozuomba. (2017) "Development Of Strict Differential Seeded Secant Numerical Iteration Method For Computing The Semi Major Axis Of A Perturbed Orbit Based On The Anomalistic Period." *Development 1.8 (2017). Science and Technology Publishing (SCI & TECH) Vol. 1 Issue 8, August – 2017*
24. Ogbonna Chima Otumdi , Ozuomba Simeon, Philip M. Asuquo (2020) Device Hardware Capacity And Rssi-Based Self Organizing Map Clustering Of 928 Mhz Lorawan Nodes Located In Flat Terrain With Light Tree Densities *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 9, September - 2020*
25. Simeon, Ozuomba Ozuomba (2014) "Comparative Evaluation of Initial Value Options For Numerical Iterative Solution To Eccentric Anomalies In Kepler's Equation For Orbital Motion." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 1 Issue 5, December - 2014*
26. Atakpo, F. K., Simeon, O., & Utibe-Abasi, S. B. (2021) A COMPARATIVE ANALYSIS OF SELFORGANIZING MAP AND K-MEANS MODELS FOR SELECTION OF CLUSTER HEADS IN OUT-OF-BAND DEVICE-TO-DEVICE COMMUNICATION. *Journal of Multidisciplinary Engineering Science Studies (JMESS).*
27. Simeon, Ozuomba (2014) "Fixed Point Iteration Computation Of Nominal Mean Motion And Semi Major Axis Of Artificial Satellite Orbiting An Oblate Earth." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 1 Issue 4, November – 2014*
28. Idio, Uduak, Constance Kalu, Akaninyene Obot, and Simeon Ozuomba. (2013) "An improved scheme for minimizing handoff failure due to poor signal quality." In *2013 IEEE International Conference on Emerging & Sustainable Technologies for Power & ICT in a Developing Society (NIGERCON)*, pp. 38-43. IEEE, 2013.
29. Simeon, Ozuomba. (2015) "Development of Closed-Form Approximation of the Eccentric Anomaly for Circular and Elliptical Keplerian Orbit." Development 2.6 (2015). *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 2 Issue 6, June - 2015*
30. Arago, N. M., Galido, E. A., Padilla, M. V. C., Tulin, L. M., Virrey, G. C., & Velasco, J. S. (2020). Long range communication technology for weather buoy. *International Journal of Emerging Trends in Engineering Research*, *8*(8).
31. Sasmita, E. S., Rosmiati, M., & Rizal, M. F. (2018, December). Integrating forest fire detection with wireless sensor network based on long range radio. In *2018 International Conference on*

Control, Electronics, Renewable Energy and Communications (ICCEREC) (pp. 222-225). IEEE.

32. Feng, X., Yan, F., & Liu, X. (2019). Study of wireless communication technologies on Internet of Things for precision agriculture. *Wireless Personal Communications*, *108*(3), 1785-1802.
33. Săcăleanu, D. I., Manciu, I. P., & Perişoară, L. A. (2019, June). Performance analysis of LoRa technology in wireless sensor networks. In *2019 10th IFIP International Conference on New Technologies, Mobility and Security (NTMS)* (pp. 1-5). IEEE.
34. Samuel, Wali, Simeon Ozuomba, and Philip M. Asuquo (2019). EVALUATION OF WIRELESS SENSOR NETWORK CLUSTER HEAD SELECTION FOR DIFFERENT PROPAGATION ENVIRONMENTS BASED ON LEE PATH LOSS MODEL AND K-MEANS ALGORITHM. EVALUATION, 3(11). *Science and Technology Publishing (SCI & TECH) Vol. 3 Issue 11, November - 2019*
35. Samuel, W., Ozuomba, Simeon, & Constance, K. (2019). SELF-ORGANIZING MAP (SOM) CLUSTERING OF 868 MHZ WIRELESS SENSOR NETWORK NODES BASED ON EGLI PATHLOSS MODEL COMPUTED RECEIVED SIGNAL STRENGTH. *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 6 Issue 12, December - 2019*
36. Njoku, Felix A., Ozuomba Simeon, and Fina Otosi Faithpraise (2019). Development Of Fuzzy Inference System (FIS) For Detection Of Outliers In Data Streams Of Wireless Sensor Networks. *International Multilingual Journal of Science and Technology (IMJST) Vol. 4 Issue 10, October - 2019*
37. Simeon, Ozuomba. (2020). "APPLICATION OF KMEANS CLUSTERING ALGORITHM FOR SELECTION OF RELAY NODES IN WIRELESS SENSOR NETWORK." *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 6, June - 2020*
38. Simeon, Ozuomba. (2020). "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. 7 Issue 12, December - 2020*
39. Kalu, C., Ozuomba, Simeon. & Udofia, K. (2015). Web-based map mashup application for participatory wireless network signal strength mapping and customer support services. *European Journal of Engineering and Technology, 3 (8)*, 30-43.
40. Johnson, Enyenihi Henry, Simeon Ozuomba, and Ifiok Okon Asuquo. (2019). Determination of Wireless Communication Links Optimal Transmission Range Using Improved Bisection Algorithm. *Universal Journal of Communications and Network, 7(1), 9-20.*
41. Palattella, M. R., & Accettura, N. (2018, October). Enabling internet of everything everywhere: LPWAN with satellite backhaul. In *2018 Global Information Infrastructure and Networking Symposium (GIIS)* (pp. 1-5). IEEE.
42. Fraire, J. A., Céspedes, S., & Accettura, N. (2019). Direct-to-satellite IoT-a survey of the state of the art and future research perspectives: Backhauling the IoT through LEO satellites. In *Ad-Hoc, Mobile, and Wireless Networks: 18th International Conference on Ad-Hoc Networks and Wireless, ADHOC-NOW 2019, Luxembourg, Luxembourg, October 1–3, 2019, Proceedings 18* (pp. 241-258). Springer International Publishing.
43. Palazzi, V., Bonafoni, S., Alimenti, F., Mezzanotte, P., & Roselli, L. (2019). Feeding the world with microwaves: How remote and wireless sensing can help precision agriculture. *IEEE Microwave Magazine*, *20*(12), 72-86.
44. Trasviña-Moreno, C. A., Blasco, R., Marco, Á., Casas, R., & Trasviña-Castro, A. (2017). Unmanned aerial vehicle based wireless sensor network for marine-coastal environment monitoring. *Sensors*, *17*(3), 460.
45. Cui, M., Zhang, G., & Zhang, R. (2019). Secure wireless communication via intelligent reflecting surface. *IEEE Wireless Communications Letters*, *8*(5), 1410-1414.
46. Lee, W. C. (2010). *Mobile communications design fundamentals*. John Wiley & Sons.
47. Ai, B., Cheng, X., Kürner, T., Zhong, Z. D., Guan, K., He, R. S., ... & Briso-Rodriguez, C. (2014). Challenges toward wireless communications for high-speed railway. *IEEE transactions on intelligent transportation systems*, *15*(5), 2143-2158.
48. Tang, W., Chen, M. Z., Chen, X., Dai, J. Y., Han, Y., Di Renzo, M., ... & Cui, T. J. (2020). Wireless communications with reconfigurable intelligent surface: Path loss modeling and experimental measurement. *IEEE Transactions on Wireless Communications*, *20*(1), 421-439.
49. Chimaobi, N. N., & IfeanyiChimaNnadi, C. P. N. (2017). Comparative Study of Least Square Methods for Tuning CCIR Path Loss Model. *Communications*, *5*(3), 19-23.
50. Faruk, N., Adediran, Y. A., & Ayeni, A. A. (2013, July). Error bounds of empirical path loss models at VHF/UHF bands in Kwara State, Nigeria. In *Eurocon 2013* (pp. 602-607). IEEE.
51. Stephen, M. A., David, O. O., & Oludare, A. M. (2018). Adaptation of Path Loss Models for Terrestrial Broadcast in VHF Band in Minna City, Niger State, Nigeria. *IUP Journal of Telecommunications*, *10*(3).