International Journal of Electronics Communication and Computer Engineering
Volume 13, Issue 2, ISSN (Online): 2249–071X

Heuristical Evaluation of Signal Loss at Millimeter Wave Band

Adewale Abe[1], Oladunni Juliet Femi-Jemilohun[2], Emmanuel Taiwo Fasina[3] and Bankole Adebanji[4]
[1,2,3,4]Department of Electrical and Electronic Engineering, Ekiti State University, Ado Ekiti, Nigeria.
*Corresponding author email id: oladunni.femi-jemilohun@eksu.edu.ng

Date of publication (dd/mm/yyyy): 05/05/2022

***Abstract* – This paper investigates the empirical performances of ad hoc wireless networks deployed on IEEE802.11ad standard to evaluate the signal loss propagation at millimeter wave spectrum of 60GHz for real time application. The scattering and reflective effects at this frequency band as signals propagate through the walls of corridor in a specified office setting were considered. The potentials of this spectrum band to delivered Gigabytes data throughput for live streaming, enormous system reliability, and capacity in the location of choice were revealed. These potentials have positioned this short range, high speed communication systems as a preferred option for effective performance in wireless indoor propagation. Also the predicted path loss which is lower than the free space propagation path loss results in aggregate high data rate, hence improved system performance is achieved.**

***Keywords* – Millimeter Wave, Oxygen Absorption, IEEE802.11ad, Throughput, Gigabytes, Airfiber Wireless Link.**

I. Introduction

The driving impetus for new technology that supplement the capacity of conventional Wi-Fi is the quest for faster speeds, high capacity and low latency. This demand led to the release of the first 802.11ad wireless device (WiGig dock D5000) in 2013 to establish 60 GHz link with compatible latitude 6430u equipped with Wilocity chipset to produce multi-gigabit speed in support of advanced applications [1]. WiGig uses four channels ranging from 58.32 to 64.80 GHz, but only channel 2 having center frequency of 60.24 GHz is available worldwide. Data transmission has attracted much attention since the standardization of 802.11ad consumer devices running on millimeter wave range. Globally, the availability of the 60 GHz as unlicensed spectrum has spurred interest in gigabit-per-second wireless communication for short range applications.

The 802.11ad standard divides the 60 GHz frequency band into four channels each with a bandwidth of 2.16 GHz allowing data rates up to 6.7 Gbits/s [2]. As radio signals travel, they interact with objects and their medium or channel of communication. For this reason, radio signals can be reflected, refracted or diffracted. Hence wireless signal suffered impairments from reflection, refraction or diffraction of these signals. The capability and effectiveness of the receiver to receive the sending signal and consequently free or clean it from associated interferences, attenuation, noise, and distortion presents a huge challenge. It is essential to evaluate the path loss of radio signal at 60 GHz band as it will help in the determination of many components of radio communications system or wireless system, also the levels of the loss for specific radio path, signal strength at each location [3]. Out of the several causes of radio path loss, this work will focus mainly on 60GHz FSPL. As a result of increase free space path loss (FSPL), and propagation losses arising from materials (atmospheric and oxygen absorption), and shadowing of human body, transmission at 60 GHz is over a short distance of about 10m [4] [5] [6]. Equation 1 according to [5] is generally used for calculating FSPL irrespective of the frequencies.

$$\text{FSPL (dB)} = 20 \log10 f + 20 \log10 d + 32:4 \qquad (1)$$

Where d is the distance between the transmitter and the receiver in meters and f represents signal frequency in MHz. It can be deduced from (1) that the free space loss would increase by 6 dB whenever the frequency or distance is doubled. Assuming that the transmission is in LOS, then the path loss is solely governed by free space propagation formula given as:

$$Pl = 20\log 10\ [4\pi d] \quad (2)$$

Where λ is the operating wavelength. It can be deduced from (2) that path loss increases as the distance of transmission increases or when the wave length decreases as revealed in Table 1.

Table 1. Comparison of Path Losses for mobile communication frequencies in free space at different ranges.

Distance (m)	fc = 2.4 GHz	fc = 5 GHz	fc = 60 GHz
1	-40.0 dB	-46.4 dB	-68.0 dB
2	-46.2 dB	-52.4 dB	-74.0 dB
3	-49.6 dB	-55.9 dB	-77.5 dB
4	- 52.1 dB	-58.5 dB	-80.0 dB
5	-54.0 dB	-60.4 dB	-81.9 dB
6	- 55.6 dB	-61.9 dB	-83.6 dB
7	-56.9 dB	-63.3 dB	-84.9 dB
8	-58.1 dB	- 64.5 dB	-86.1 dB
9	-59.1 dB	-65.6 dB	-87.1 dB
10	-60.0 dB	-66.4 dB	-88.0 dB
11	-60.9 dB	-67.2 dB	-88.8 dB
12	-61.6 dB	-68.0 dB	-89.6 dB
13	-62.3 dB	-68.7 dB	-90.3 dB
14	-62.9 dB	-69.3 dB	-90.9 dB
15	- 63.6 dB	-69.9 dB	-91.5 dB
16	-64.1 dB	- 70.5 dB	-92.1 dB
17	-64.7 dB	-71.0 dB	-92.6 dB
18	-65.2 dB	- 71.5 dB	-93.1 dB
19	-65.6 dB	- 72.0 dB	-93.6 dB
20	-66.1 dB	- 72.4 dB	-94.0 dB

Recently, the unlicensed products of the WLAN running on carrier frequency of 2.4 GHz have moved to 5 GHz. Increasing the radio frequency channel bandwidth for mobile radio channels will significantly increase data capacity and reduce latency caused by heavy digital traffic. The perceived oxygen absorption loss of about 20 dB/km is minimal when the transmission is not more than 100 m. According to Samsung [6], mm Wave spectrum can be used for cellular networks since recent results show the feasibility of transmitting above 8 Gbps data over mm Wave cellular for distance greater than 2km. As discussed in [7, 8], wave propagation inside tunnels depends not mainly on the carrier frequency and properties of the tunnel, but equally varies along separating distance between transmit--ter and receiver. The propagation is influenced by the free-space mechanism. Eventually, when the user is at the farthest, attenuation of reflected rays caused the disappearance (fading or dispersion) of wave guiding effects.

II. Related Work

Several experimental works have been carried out under NLO Sindoor environments. Often, the out comes of such researchers are approximated by some models. Comparing various results from several authors becomes a challenge. Moreover, it seems practical to analyze the effect of such propagation mechanism with the experimental results and models presented. Few researche--rs have investigated propagation characteristics at 38 GHz and 78 GHz bands. The works [10] and] [11] [12] evaluated mm Wave band propagation characteristics with very good results. Their findings reveal that in NLOS environments path loss is slightly higher than in ultra-high frequency (UHF) and microwaves bands because of the higher carrier frequency. On the other hand, the paper [13] investigated the effects of 802.11g/n signal propagation through homogeneous walls and proposed signal path loss in NLOS environments. The study [14] investigates 24 GHz GbE wireless data communication in non-line-of-sight indoor environments by using commercial 24GHz PTP Ubiquiti air fiber wireless link, the results shows the possibility of providing 1.25 Gbps aggregated data rates when wireless systems are deployed in typical modern building environments which is prone to obstructions by construction materials. With the standardization of 802.11ad devices, there is few number of studies invest in gating this standard, which would permit comprehensive assessment of radio wave propagation within buildings. Beam forming, spatial processing and smart antennas features of the WiGig device (802.11ad standard) are employed in evaluation of signal path loss at 60 GHz band. The work is recent research discovery based on signal loss propagation at 60GHz over 802.11ad in real life scenario. It involves evaluating the scattering and reflective effects of signals as it propagates through the walls of corridor in office settings.

III. Material and Methods

The locations as shown in figures 1, 2 and 3 where the experiments were conducted are within the corridors of floor 3, 4, and 5 of the Network building, School of Computing and Electronic Systems Engineering, University of Essex. The dimensions of the three corridors are presented in table 2. Measurements were such that the distance between the transmitter Tx and 802.11ad A.P were increased step by step with variation of 1 m. While a Tx with latitude 6430u equipped with wireless w1601 adapter and another latitude 6430u with Ethernet adapter local area connection served as the receiver Rx, this was connected to A.P via 1 GeE. Its DHCP and auto configuration settings were enabled.

Table 2. The dimension of the Corridors.

Floor	Level 3	Level 4	Level 5
Height (m)	2.4	2.4	2.4
Width (m)	1.5	1.2	1.2
Length(m)	35.0	35.0	35.0

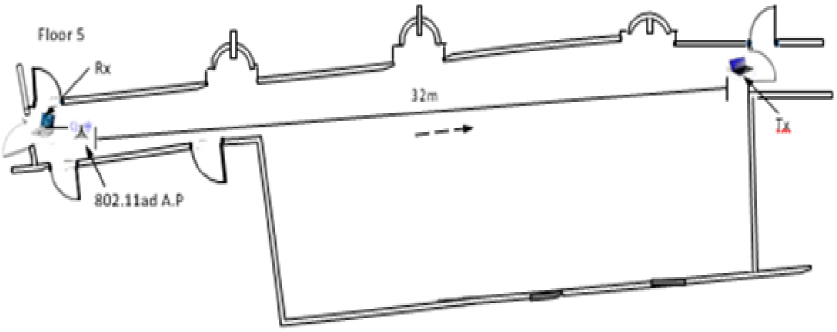

Fig. 1. Corridor 5 plan with the dashed arrow indicating the transmitter Tx moving direction.

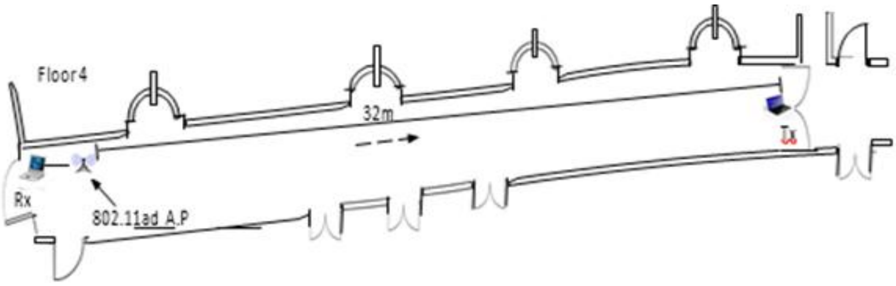

Fig. 2. Corridor 4 plan with the dashed arrow indicating the transmitter Tx moving direction.

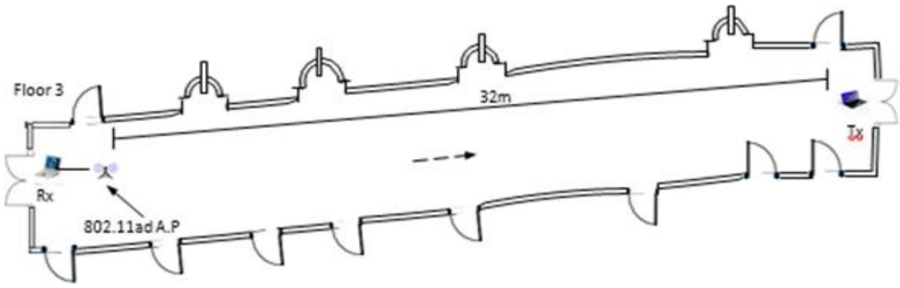

Fig. 3. Corridor 3 plan with the dashed arrow indicating the transmitter Tx moving direction.

Tx has transmission buffer of size 512 bytes, same as the Rx. Wireless A.P WiGig dock supporting 802.11ad was used as the original signal source. Transmitter Tx and the WiGig dock 802.11ad A.P established and maintained 60 GHz wireless link up to 32 m in all the corridors. According to the study [15], both the frequency of the signal and the dielectric properties of the materials of the corridor walls play significant role on the reflection and scattering of signals with in the corridor, which in turn impact on the measurement results. The walls of the corridor consist of wooden doors, plastered walls, and in some places glass. Table 3 presents the permittivity, and conductivity of these materials. Often, dielectric properties (the permittivity and conductivity) shown in table 3 is varied and largely depend on the composition, the structure and the quality of different material soft he wall [15] [16].

Table 3. The permittivity and conductivity of the materials composition of the corridors [15] [16].

Materials	Wooden Door	Glass	Plaster
Permittivity	5.8	6.06	2.49−2.82
Conductivity(S/m)	0.06	0.35	0.00

The measurements were aimed to evaluate the 802.11ad standard signal propagation under LOS conditions. With operating frequency around 60 GHz, path loss reference distance for this work was choosing to be 1m. This is to evaluate attenuation effect on the signal with respect to geometric increase in distance along the corridor. Modulation techniques according to IEEE 802.11ad specification are DBPSK/QPSK/16QAM. While the speed of the wireless link was measured from the docking status on the transmitter, the actual throughput was measured with the aid of NTttcp [17] [18] installed on Tx and Rx. This software is a Winsock- based port of the ttcp tool that measures networking performance in terms of bytes transferred per second and CPU cycles per byte. Ten different measurements (throughputs and link speed) were recorded at each distance and average values obtained. For this experiment, a heuristic approach was used in converting the magnitude of the channel link speed against corresponding distance to determine the respective signal loss in dBm.

IV. Results and Discussion

Propagation at mm Wave frequencies is short range, thus as can be seen from the plot of the received signal level against distance in figure 4 and in table 4. Attenuation on each floor is different as a result of changes in the environment and/or distance along the radio path which affect propagation characteristics [3].

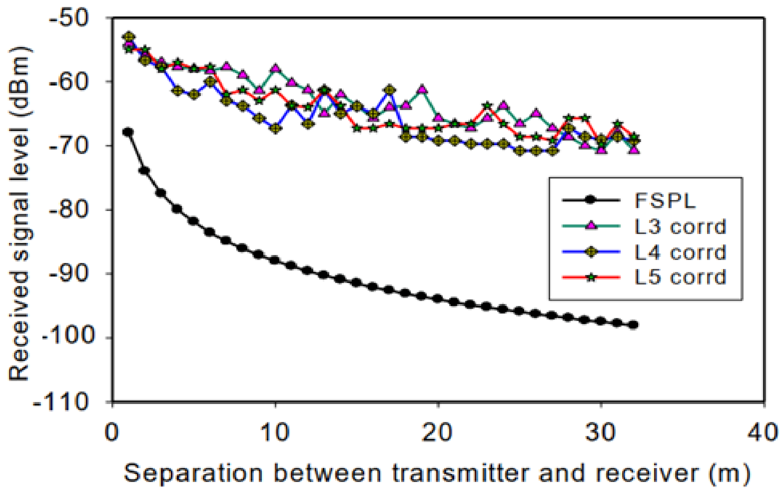

Fig. 4. Received signal strength against separation between the transmitter and the WiGig dock 802.11ad standard.

Table 4. Heuristic path loss values for floor 3, 4, 5 and Fspl at 60 GHz.

Distance (m)	FSPL	Floor 3	Floor 4	Floor 5
1	-68	-54	-53	-55
2	-74	-56	-56.7	-55
3	-77.5	-57	-57.7	-58
4	-80	-57.7	-61.4	-57
5	-81.9	-58	-62	-58

Distance (m)	FSPL	Floor 3	Floor 4	Floor 5
6	-83.6	-58.3	-60	-57.7
7	-84.9	-57.7	-63	-62
8	-86.1	-59	-63.8	-61.3
9	-87.1	-61.4	-65.7	-63
10	-88	-58	-67.3	-61.3
11	-88.8	-60.2	-63.7	-63.8
12	-89.6	-61.3	-66.6	-64
13	-90.3	-65	-61.3	-61.3
14	-90.9	-62	-65	-63.8
15	-91.5	-63.8	-63.85	-67.3
16	-92.1	-65.7	-65	-67.3
17	-92.6	-64	-61.3	-66.6
18	-93.1	-63.8	-68.6	-67.3
19	-93.6	-61.3	-68.6	-67.3
20	-94	-65.7	-69.2	-67.3
21	-94.5	-66.6	-69.2	-66.6
22	-94.9	-67.3	-69.7	-66.6
23	-95.2	-65.7	-69.7	-63.8
24	-95.6	-63.8	-69.7	-66.6
25	-95.9	-66.6	-70.8	-68.6
26	-96.3	-65	-70.8	-68.6
27	-96.6	-67.3	-70.8	-69.2
28	-96.9	-68.6	-67.3	-65.7
29	-97.3	-70	-68.6	-65.7
30	-97.5	-70.8	-69	-69.8
31	-97.8	-68	-68.6	-66.6
32	-98.1	-70.8	-69.2	-68.6

As revealed in table 4, the propagation loss in floor level 3 varies between -54dB and -59dB at distances between 1m and 10m with the exception noticeable at 9m distance given a loss of 61.4dB. However, at distance of 11m, the signal loss varies steadily with a pockets of fluctuations until a signal loss of -70.8 was recorded at a distance of 32m. In comparison with floor level 4 and 5, signal losses of -53dB and -67.3dB, -55dB and -63dB respectively were recorded between distances of 1m and 11m. beyond these points propagation losses vary considerably reaching maximum values at distance of 27m for both floors. However, the propagation losses in all the floor levels are lower than the losses in the free space at the same distances. This confirms the effect of oxygen absorption on the signal being high at the free space propagation and negligible in a confined place like the experimental scenarios under consideration. With the WiGig dock as the A.P, the 802.11ad signal propagation loss results seems to be much higher than the FSPL model results over same distance as can be seen in Fig 4. This shows the capability of the 802.11ad device to offer improved system performance with its better signal propagation in contrast towhat is obtainable with FSPL. Generally, the path loss is considerably higher in corridor 3 than the other two corridors up to 14m. As the separation between Tx and 802.11ad A.P widens, the attenuation is lower in L3 than at L4, and L5 corridors. It seems reflection is much stronger at longer distance on floor 3 [19]. This suggest that corridor scan serve as wave-guides to reduce the effects of multi path fading [20] [21]. The wave guiding is stronger in L 3 than in L 5 and L 4 corridors. Table 5 depicts the link capacity (limited by 1 GbE) and corresponding data rates within the corridors measured over same distance.

Table 5. Data rates within the corridors.

Floor	Level 3	Level 4	Level 5
Link capacity Gbps	1	1	1
Data rates (Mbps)	948	943	946
Separation (m)	32	32	32

It can be seen from table 5 that the data rates measured in real-time within the corridors between the Tx and the Rx is between 943 Mbps to 948 Mbps from maximum link speed of 1 Gbps. This equates to bandwidth utilization or performance efficiency of about 94.3%. This is in contrast to the maximum data rate of 670 Mbps produced by channel capacity of 743 Mbps with performance efficiency of 80%-90% in study [14]. By comparing the experimental results with the free space loss models, a new model for thee valuation of propagation of 60GHz signals along the corridor was proposed. The use of higher frequency as means of communication within building looks promising than the narrow bandwidth peculiar to lower frequencies susceptible to frequency and spatial selectivity's. Although some studies have shown propagation is effective from 900 MHz up to GHz bands [21] [22].

V. Conclusion

The results as presented here seem better since the signal loss is far lower than FSPL. This research might be useful to establish a concise knowledge of the 60 GHz propagation and can be deployed for network design and interference analysis of advanced communication systems in railways. The high data rates achieved during propagation along the corridors, establishes the fact that the waveguide like effects of the corridor enhanced the signal throughput through reflection, since the aggregate data rate is high as revealed in the results, thus improved system performance is achieved. Showing that hallway/corridor as well as typical office can be flooded with gigabit/s through wireless transmission to enable seamless communication and adequate bandwidth requirement for multimedia applications services engaged in such environment.

Acknowledgement

This work is sponsored by the Federal Government of Nigeria through the Tertiary Education Trust Fund (T-

-ETFUND) scheme.

REFERENCES

[1] W. Alliance, “WigigR and the future of seamless connectivity,” 2013.

[2] B. Schulz, “802.11ad - wlan at 60 ghz a technology introduction." White paper, Rohde and Schwarz, 2013.

[3] P. Series, “Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 mhz to 100 ghz," Recommendation ITU-R, 2012.

[4] O.J. Femi-Jemilohun & S.D. Walker “Effects of diffraction propagation at 24GHz spectrum Band” Transactions on Networks and Communications, 2-015, 53-63.

[5] O.J. Femi-Jemilohun & S.D. Walker “Pathloss prediction models for corridor propagation at 24GH” Transactions on Networks and Communications, 2014, 2, 84-94.

[6] S. Grobart “Samsung announces new’ 5g’ wireless technology” 2013.

[7] K. Guan, Z. Zhong, B. Ai, R. He, B. Chen, Y. Li, and C. Briso-Rodriguez, “Complete propagation model in tunnels," IEEE Antennas and Wireless Propagation Letters, 12, 2013 pp.741-744.

[8] C. Cerasoli, “Rf propagation in tunnel environments".IEEE MILCOM 2004, 1, pp363-369.

[9] G.R. MacCartney and T. S. Rappaport, “73 ghz millimeter wave propagation measurements for outdoor urban mobile and backhaul communications in new york city," IEEE International Conference on Communications (ICC),2014 pp. 4862-4867, IEEE.

[10] J.N. Murdock, E. Ben-Dor, Y. Qiao, J.I. Tamir, and T.S. Rappaport, “A38 ghz cellular outage study for an urban outdoor campus environment" Wireless Communications and Networking Conference (WCNC), 2012 pp.3085-3090.

[11] T. S. Rappaport, Y. Qiao, J. I. Tamir, J. N. Murdock, and E. Ben-Dor, “Cellular broadband millimeter wave propagation and angle of arrival for adaptive beam steering systems" Radio and Wireless Symposium (RWS), 2012 pp. 151-154.

[12] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G.N. Wong, J.K. Schulz, M. Samimi, and F. Gutierrez, “Millimeter wave mobile communications for 5g cellular: It will work!” Access, IEEE, 2013, 1, pp. 335-349. 2013.

[13] S. Japertas, E. Orzekauskas, and R. Slanys, “Research of ieee 802.11 standard signal propagation features in multi partition indoors" Digital Information Processing and Communications (ICDIPC), 2012 Second International Conference on, pp. 1-4.

[14] O.J. Femi-Jemilohun, T. Quinlan, S. Barc, and S. D. Walker, “An experimental investigation into gbe wireless data communication at 24 ghzin non-line-of-sight and multipath rich environments" IEEE Antennas and Wireless Propagation Letters, 2014, 13, pp. 1219-1222.

[15] R. Wilson, “Propagation losses through common building materials 2.4 ghz vs 5ghz," Magis Networks Inc.: San Diego, CA, USA, 2002.

[16] H. Sugimoto and T. Sato, “Experimental results of 2.45, 3.5, 5, and 10ghz radio propagation characteristics" IEEE 65th Vehicular Technology Conference-VTC2007-Spring, 2007, pp. 339-343.

[17] H. Budiarto, K. Horihata, K. Haneda, and J.-i. Takada, “Experimental study of non-specular wave scattering from building surface roughness for the mobile propagation modeling" IEICE transactions on communications, 87, (4), 2004, pp. 958-966.

[18] Microsoft, “How to use ntttcp to test network performance." online, March 2008.

[19] P. Smulders and L. Correia, “Characterization of propagation in 60 ghz radio channels" Electronics & communication engineering journal, 1997,9,(2), pp.73-80.

[20] J. Michel et al., “Time-reversal uwb wireless communication-based train control in tunnel" 2009

[21] R. Klingler, “Radio coverage for road and rail tunnels in the frequency range 75 to 1000 mhz," Vehicular Technology Conference, 1991. Gateway to the Future Technology in Motion., 41st IEEE, 1991 pp. 433-438.

[22] Y.P. Zhang and H. Hong, “Ray-optical modeling of simulcast radio propagation channels in tunnels" IEEE transactions on vehicular technology, 2004, 53, (6), pp. 1800-1808.

AUTHOR’S PROFILE

First Author
Adewale Abe, received the B.Eng. degree in the Electrical and Electronic Engineering in 1999 from then Ondo State University, Ado-Ekiti, Ekiti State, Nigeria (now Ekiti State University, Ado-Ekiti), M.Eng. degree (Electrical and Electronic Engineering) from University of Benin, Nigeria in 2005 and PhD degree (Electronic System Engineering and Machine) from University of Essex, UK in 2018. His research interest are Electronic and telecommunication engineering, Millimeter-Wave propagation, 4k Video transmission. He is a registered COREN. Engineer and a member of Nigerian Society of Engineers (MNSE). He is Senior lecturer in the Electrical and Electronic Engineering department of Ekiti State University, Ado-Ekiti, Nigeria.

Second Author
Femi-Jemilohun Oladunni Juliet, is an Associate Professor in the Department of Electrical and Electronic Engineering, Ekiti State University Ado-Ekiti. She obtained her Beng from the Ondo Stae University in 1998, Meng (Communications Engineering) from Federal University of Technolgy, Akure, Ondo State and PhD (Wireless Communications) from University of Essex, United Kingdom in year 2010 and 2015 respectively. Her research interests are in wireless communications and Millimeter Wave propagations and power line communication. She is a member of the following professional organizations: Nigerian Society of Engineers (NSE), Council for the Regulation of Engineering in Nigeria (C-OREN), and Institute of Electrical and Electronic Engineers (IEEE).

Third Author
Adebanji Bankole, received the B.Eng. degree in Electrical and Electronic Engineering in 1997 from the then Ondo State University, Ado-Ekiti, Ekiti State, Nigeria (now Ekiti State University, Ado-Ekiti), M.Tech. degree (Electronic and Electrical Engineering) and Ph.D degree (Power System Engineering and Machine) from Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria in 2010 and 2019 respectively. His research interest are renewable energy, Power system engineering, Hybrid, Small hydro and optimization. He is a registered COREN Engineer and a member of Nigerian Society of Engineers (MNSE). He is currently a Senior lecturer in the Electrical and Electronic Engineering dep-artment of Ekiti State University, Ado-Ekiti, Nigeria.

Forth Author

Fasina Taiwo, received the B.Eng. degree in Electrical and Electronic Engineering from Ondo State University, Ado Ekiti, Nigeria (now Ekiti State University, Ado-Ekiti), in 1998 and M. Tech. degree from Ladoke Akintola University (LAUTECH), Ogbomoso, Nigeria in 2012. He completed his Ph.D. from Cardiff University, United Kingdom, in 2019. He is currently a Senior lecturer in Ekiti State University, Ado Ekiti, Ekiti-State, Nigeria. He is a registered COREN Engineer and a member of the Nigerian Society of Engineers (MNSE). His main interest includes power system analysis and control, distributed generation, localized energy systems, smart grid, Electric vehicles, deregulation, and electricity tr--ansmission pricing.