Impact of Household Construction Materials on 4G Signal

A. Musa[1,2] and B. S. Paul[1]
[1]Institute for Intelligent Systems, University of Johannesburg, South Africa
[2]Centre for Telecommunication Research and Development, Kwara State University, Malete, Nigeria
twhid2001@yahoo.com

***Abstract*—Different household construction materials cause significant losses when subjected to wireless signals along propagation path. A change in signal strength and losses occur as a result of the complex composition of the materials. This paper investigates the impact of construction materials on fourth generation (4G) signal in terms of Received Signal Strength (RSS), upload and download speed and jitter. The steps taken involve finding the penetration loss from the RSS with their respective data representation and drawing fact from the represented data. The results show that Material B (agba - gosswei lerodendrin balsamic ferum) and Material D (concrete) have 12.9% decrease in indoor signal strength. Also, for indoor received signal strength, Material E (reflective glass) has 20.6% decrease, Material C (iroko - chlorophora excels) has 18.7% decrease while Material A (apa – afzelia Africans) has 43.8% decrease. The results from Quality of Service (QoS) parameter (jitter) are compared with outdoor and indoor. Relatively, it shows that materials B, D, C and E provide improved experience to the users.**

Keywords—4G, RSS, jitter, penetration loss, upload speed, download speed, packet loss.

I. INTRODUCTION

The need to measure wireless signal parameters is important in every enterprise to determine the quality of service (QoS) obtained from the network. It is very rampant in buildings whereby the mobile users tend to change position from one point to another in other to have a reliable wireless communication. The quality of wireless signal is reduced when they are obstructed by different materials along the path of propagation. The density, coverage, signal power and other related metrics are to be known in different environmental conditions. Researchers have worked on radio waves propagation in building and statistical results were obtained from their measurements [1] – [3].

Wireless signals generated by Radio Frequency (RF) circuit or device are affected by various properties which can be categorized into intrinsic or extrinsic properties. The intrinsic properties refer to the factors that affect the wireless signals internally within the sources where they are generated. Examples include short and thermal noise etc. This scenario is commonly affected by RF devices, such as router and RF antenna operating within 900/1800MHz, 2100MHz and 2400MHz. The extrinsic properties refer to the factors that tend to distort wireless signal externally relative to their environment immediately after they are directed away from the sources.

There is little awareness in the construction industry regarding the impact of wireless coverage when it is subjected to different construction materials. A change in building materials to meet the requirement for building regulation needs to be known, such that it can improve the efficiency of the signals. Some materials can help to improve the thermal conductivity properties of houses but can affect the transmission of wireless signals into and within houses [4].

The loss experienced by radio waves when subjected to different materials depends on the frequency and angle of incidence of the waves as well as the materials properties. An approved recommendation by Radiocommunication Sector of the International Telecommunication Union i.e. ITU-R (P.2014) defines the basic quantities related to the electrical properties of a building materials and penetration loss which describe the effect of the material structure, electrical properties and building loss measurement on radio propagation [4].

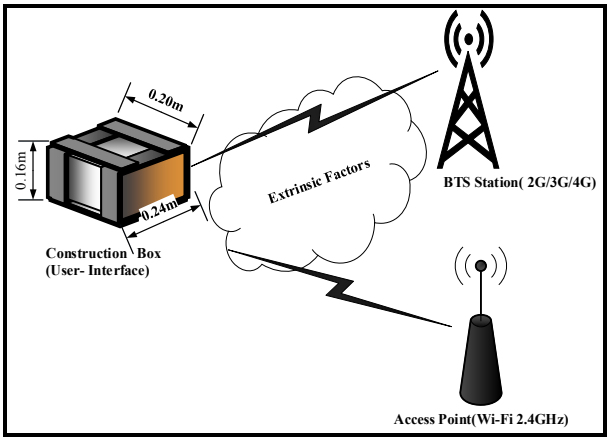


Fig. 1. Physical model illustration of the research work.

Fig. 1 gives the physical model of the study showing the Base Transceiver Station having fourth generation (4G) signal for wireless communication. The enclosure is subjected to 4G signal and predictive measurement is required for both indoor and outdoor scenarios.

The coverage of RF signal is further decreased by the impact caused by various household materials. The reduction in signal strength is indicated in Table I for various materials.

Table I. Radio Coverage Reduction Loss [5].

S/N	Materials	Range of Reduction of loss
1	Wood, plaster, glass uncoated, without metal	0 - 10 %
2	Brick, Press Board	5 - 35 %
3	Ferro concrete	10 - 90 %
4	Metal, aluminum lining	15-95%

Customers or end-users demand good QoS and coverage. The penetration loss caused by different household construction materials affect signal strength received by the end users. The penetration loss is significant while considering the overall losses in wireless communication [6].

The survey metrics in this work introduce the various parameters to be measured using optimum software and hardware devices to detect and measure the metrics that are used as judging criteria to evaluate the QoS experience by the end users for various household construction materials as wireless signal propagate through them. User experience on a given network service differs based on their environment and the medium through which the wireless signal has travelled. The absorption rate of different household construction materials through which wireless signals travel differs from one another. The building materials considered in this work are non-magnetic and dielectric but behave like a lossy dielectric material since they allow signal to penetrate through them.

The unrealistic propagation of the wireless signal when it passes through various medium which is caused by multipath has made it penetrate through various construction materials having different characteristics which account for significant penetration loss. The metrics of focus in this work therefore include Received Signal Strength (RSS), penetration loss, download speed, upload speed, packet loss and jitter.

This work presents the impact of construction materials on 4G signal by evaluating the QoS in different household materials. The need to effectively communicate wirelessly cannot be over emphasised. The QoS to the end user is a function of various materials characteristics through which signals have been propagated; hence the need to evaluate the losses encountered in various construction materials. This is essential to enhance proper planning and adequate provision for the total losses in a building. Unlike other related works, different study areas and more household construction materials as well as propagation parameters and metrics have been investigated.

The related works have been presented in Section II. Section III discusses the methodology, while the results are discussed in Section IV. Conclusion is drawn in Section V.

II. RELATED WORKS

The work in [8] presented the method used to determine the Global System for Mobile Communication (GSM) signal provided by four service providers. Focus was on the penetration loss in five selected buildings constructed with different materials. The measured data was obtained using a Tecno tablet installed with Radio Frequency Signal Tracker (RFST) software. The surveyed parameters were signal strength, and distance, from which the penetration losses were obtained. The data were evaluated using Least Square Line Analysis to obtain the line that best fits the curve. The result obtained showed that the building with alucoboard wall cladding has the highest signal penetration loss while the sandcrete building/unrusted corrugated iron sheet roof has the lowest signal penetration loss. However, the signal to noise ratio (SNR) was not considered. This could be a bottle neck for wireless signal in the environment where external sources contribute majorly to signal distortion.

The work in [9] examined the penetration loss of doors and windows made of different materials inside residence using Integrated Service Digital Network Broadcast-Terrestrial (ISDB-T) Television signal operating at 677 MHz frequency. It demonstrated the signal parameters such as received power (indoor and outdoor), SNR, field strength with the aid of spectrum analyzer which was connected to ultra-high frequency (UHF) antenna. The indoor signal was measured and compared with the outdoor signal. The discrepancy was used as the penetration loss, as a result of the material characteristics which causes signal degradation. The result obtained from the average penetration loss was computed and compared using commutative distribution function (CDF) in a probability distribution curve which showed the average penetration loss (APL) decreasing from heavy to light materials.

More concerned was made on interference by using a desk set spectrum analyzer which aid visualization of operating signal in frequency and time domain. However, as a result of low power level in the device, it might not display accurate result of the surveyed data.

[10] investigated GSM signal loss in a multi-story building. Measurement was carried out in different building using the service obtained from four service providers to determine the signal strength with the aid of an RFST. The measurement was conducted outside and inside each floor of the building and the difference were computed. The result obtained showed that the loss varies between 3.09 and 3.91 which was as a result of the effect caused by floor partition. The average path loss and the floor attenuation factor were determined as 3.53 and 21.22 respectively, while the standard deviation varied from 3.46 and 6.27. It was concluded that the penetration losses were higher at the ground floor than the fifth floor. However, the fifth floor has the maximum floor attenuation factor.

The GSM signal strength level inside and outside three selected buildings was investigated by [11]. The work made use of Network Signal Info Pro software to determine the Received Signal Strength Indication (RSSI), distance and associated location parameters from appropriate Base Transceiver Station (BTS) for various environments. The RSSI was obtained for the buildings. The penetration loss for three network operators was computed for the buildings tagged B1, B2 and B3 and the mean value was obtained. Comparison was made between the theoretical and measured pathloss for both indoor and outdoor. The result showed that the measured pathloss agreed with the theoretical pathloss for the selected buildings. B1 with hollow structure had the lowest penetration loss while B3 had the highest penetration loss. The authors concluded that the construction materials affect GSM signal level inside the building which also depend on the reference point at which signal was measured.

III. METHODOLOGY

This work was carried out at Kwara State University, Malete and Ilorin region of Nigeria. The university campus consists of vegetation, students and sparsely located buildings and trees, while Ilorin consists of condensed buildings with little vegetation.

A. Description of Materials

Five construction materials which include three timber species, concrete slab, and a glass reflective have been considered. The materials were categorized as Material A (*apa*

– *afzelia Africans)*, Material B (*agba-gosswei lerodendrin balsamic ferum*), Material C (*iroko - chlorophora excels*), Material D (concrete) and Material E (reflective glass).

Fig. 2. shows the construction materials being investigated. It is an enclosure of 0.24 m × 0.20 m × 0.16 m dimension comprising three timber species i.e. *chlorophoral excels (iroko), Afzelia Africans (apa) and gosswei lerodendrin balsamic ferum (agba)*; a reflective glass and solid reinforced concrete.



Fig. 2. The different construction materials.

B. Software and Hardware Setup

To achieve the aim of this work, an android smart phone, version 8.0.0 (ABCDEF-180604V15) of model Infinix X-608 was used to measure the network parameters using RF signal tracker and Open Netttest software. The RF signal tracker used by RF engineers can measure the RSS with respect to its geolocation for selected interval of 10s. While the Open Nettest co-financed by the European Union can measure the QoS parameters which include jitter (ms), upload and download speed (Mpbs), and packet loss (%). The Open Nettest create a server which supports IPv4 and IPv6 standard which allow the network performance to be evaluated depending on the supported scheme.

C. Description of Parameters Obtained

The parameters used in this research are briefly defined below:

Receive Signal Strength (RSS): The RSS is a metric used by manufacturers to give users an indication of the signal strength their wireless device is receiving for a wireless network, measured in dBm [7].

Upload speed: This involves the interaction from the user terminal to the remote system (BTS) which was set-up for uploading data. It is measured in (Mbps).

Download Speed: This involves the interaction from the user terminal to the remote system (BTS) which was set-up for downloading data. The opposite of the upload speed was done with the download speed. It is measured in Mbps.

Jitter: This occurs as a result of packet loss. It is a measure of the delay in packet sent. It is pronounced in video conferencing and voice over internet protocol (VoIP). It is measured in ms.

Packet Loss: This occurs when one or more transmitted packets fail to arrive at its destination node. It causes observable effect in every digital communication system. It is measured in %.

$$\boldsymbol{Packet\ Loss}(\%) = \left(\frac{\boldsymbol{loss\ packet(s)}}{\boldsymbol{Total\ packets}} \times \mathbf{100}\right) \quad (1)$$

D. Determination of Penetration Loss (dBm)

The penetration loss is a measure of the absorption of wireless signal when subjected to a material having specific absorption rate. It is a loss in signal strength inside the material as compared to outside. This loss occurs in both lossy and lossless material as a result of material composition. The penetration loss is obtained using the penetration loss formula, which is defined as

$$\boldsymbol{P_{Loss}} = \sqrt{(\boldsymbol{RSS_{indoor}} - \boldsymbol{RSS_{Outdoor}})^2} \quad (2)$$

Alternatively;

$$\boldsymbol{P_{Loss}} = \boldsymbol{ABS(RSS_{indoor}} - \boldsymbol{RSS_{outdoor})} \quad (3)$$

where P_{Loss} is Penetration Loss in (dBm), ABS is a measure of the absolute value, RSS_{indoor} is the Indoor Received Signal Strength (dBm) and $RSS_{Outdoor}$ is the Outdoor Received Signal Strength (dBm).

E. Computation of the RSS Mean Value

The mean or average value of the collected data over ten samples using the RFST to measure the RSS in dBm can be expressed for the RSS_{indoor} and $RSS_{Outdoor}$ for ten sampled signal using the following expressions.

$$\boldsymbol{Average\ RSS_{indoor}} = \frac{\sum_{k=1}^{n} \boldsymbol{RSS_{Indoor_k}}}{\boldsymbol{n}} \quad (4)$$

$$\boldsymbol{Average\ RSS_{outdoor}} = \frac{\sum_{k=1}^{n} \boldsymbol{RSS_{outdoor_k}}}{\boldsymbol{n}} \quad (5)$$

Alternatively using Matlab script;

$$\boldsymbol{Average\ RSS_{outdoor}} = \frac{\boldsymbol{Sum(\ RSS_{outdoor})}}{\boldsymbol{Length(RSS_{outdoor})}} \quad (6)$$

$$\boldsymbol{Average\ RSS_{indoor}} = \frac{\boldsymbol{Sum(\ RSS_{indoor})}}{\boldsymbol{Length(RSS_{indoor})}} \quad (7)$$

where n is the total number of the sampled event.

F. Theoretical Expression for Unit Conversion

The standard referenced value of power (dBm) can be converted to watt (W) using the theoretical expression given below.

$$\boldsymbol{RSS(dBm)} = \mathbf{10}\ \boldsymbol{\log_{10}}\left(\frac{\boldsymbol{P_r}}{\boldsymbol{1mW}}\right) \quad (8)$$

where P_r is the received power by the smart phone antenna in W.

$$\boldsymbol{P_r(w)} = \mathbf{10}^{\wedge}\left(\frac{\mathbf{1}}{\mathbf{10}} \times \boldsymbol{RSS(dBm)}\right) \quad (9)$$

G. Data Collection Procedure

Procedure I: Measurement for the RSS

Using an android smart phone described earlier having RFST being installed on it accessing only 4G, the Global Positioning System (GPS) receiver of the phone was turned on to give the geo location of the mobile phone. The software user interface capable of giving the signal strength measurement was launched. The graphical and accurate numerical values of the parameters were recorded for both indoor and outdoor. Measurements were sampled for 100s at

time interval of 10s and the average values were recorded. The above procedures were repeated for materials A, B, C, D and E.

Procedure II: Measurement for the Quality of Service (QoS) Parameter

Using the same android smart phone having Open Nettest software installed on it accessing only 4G, the GPS receiver of the phone was launched to give the geographical parameters of the mobile phone. Other procedures like the ones described in Procedure I were carried out.

IV. RESULTS AND DISCUSSION

For the materials under investigation, the result obtained for both indoor and outdoor scenarios when subjected to 4G are presented in Fig. 3 to Fig. 5. Similarly, the computational mean values for analysis are also presented in Table II to Table XIII.

A. Material A

Material A, termed *Afzelia Africans (Apa)*, is one of the wood species commonly used for household constructions. The indoor and outdoor measurements are shown in Table II and Table III.

Table II. Mean value of RSS for Material A

Material	4G Indoor (dBm)	4G Outdoor (dBm)
A	**-94.6**	**-92.1**

Table III. QoS Parameter for Material A

Material A (Indoor)	
QoS Parameter	**Measured Value**
Jitter	6.70ms
Download Speed	7.5Mbps
Upload Speed	9.2Mbps
Packet Loss	0.00%
Material A (Outdoor)	
QoS Parameter	**Measured Value**
Jitter	11.2ms
Download Speed	9.8Mbps
Upload Speed	9.1Mbps
Packet Loss	25.00%

B. Material B

Material B, termed as *gosswei lerodendrin balsamic ferum (Agba)*, is another commonly used wood species for household constructions. The indoor and outdoor measurements are presented in Table IV and Table V.

Table IV. Mean value of RSS for Material B

Material	4G Indoor (dBm)	4G Outdoor (dBm)
B	**-93**	**-92.4**

Table V. QoS Parameter for Material B

Material B (Indoor)	
QoS Parameter	**Measured Value**
Jitter	11.2ms
Download Speed	9.8Mbps
Upload Speed	9.1Mbps
Packet Loss	25.00%
Material B (Outdoor)	
QoS Parameter	**Measured Value**
Jitter	2.70ms
Download Speed	7.0Mbps
Upload Speed	8.6Mbps
Packet Loss	0.00%

C. Material C

Material C is termed as *chlorophoral excels (iroko)*. It is also one of the wood species commonly used for household constructions. The indoor and outdoor measurements are illustrated in Table VI and Table VII

Table VI. Mean value of RSS for Material C

Material	4G Indoor (dBm)	4G Outdoor (dBm)
C	-94.5	-93.6

Table VII. QoS Parameter for Material C

Material C (Indoor)	
QoS Parameter	**Measured Value**
Jitter	3.71ms
Download Speed	10Mbps
Upload Speed	7.6Mbps
Packet Loss	0.00%
Material C (Outdoor)	
QoS Parameter	**Measured Value**
Jitter	11.2ms
Download Speed	9.8Mbps
Upload Speed	9.1Mbps
Packet Loss	25.00%

D. Material D

Material D is termed as concrete and is being used in building and construction works. The indoor and outdoor measurements are shown in Table VIII and Table IX.

Table VIII. Mean value of RSS for Material D

Material	4G Indoor (dBm)	4G Outdoor (dBm)
D	-93	-92.4

Table IX. QoS Parameter for Material D

Material D (Indoor)	
QoS Parameter	**Measured Value**
Jitter	3.40ms
Download Speed	7.0Mbps
Upload Speed	2.1Mbps
Packet Loss	0.00%
Material D (Outdoor)	
QoS Parameter	**Measured Value**
Jitter	11.2ms
Download Speed	9.8Mbps
Upload Speed	9.1Mbps
Packet Loss	25.00%

E. Material E

Material E is termed reflective glass which can allow low or no penetration as a result of the coatings. The indoor and outdoor measurements are illustrated in Table X and Table XI.

Table X. Mean Value of RSS for Material E

Material	4G Indoor (dBm)	4G Outdoor (dBm)
E	-93.6	-92.6

Table XI. QoS Parameter for Material E

Material E (Indoor)	
QoS Parameter	**Measured Value**
Jitter	3.83ms
Download Speed	10Mbps
Upload Speed	8.4Mbps
Packet Loss	0.00%
Material E (Outdoor)	
QoS Parameter	**Measured Value**
Jitter	11.2ms
Download Speed	9.8Mbps
Upload Speed	9.1Mbps
Packet Loss	25.00%

F. Average Value of the Penetration Loss

The mean value of the penetration loss also referred to as absorption loss as a result of the material characteristics is presented in Table XII. The average penetration loss can be computed using (2) and (3) for the five selected materials.

Table XII. Average Penetration Loss for the Materials

Material Under Test	4G Signal Penetration Loss (dBm)
A	4.5
B	0.8
C	4.3
D	4.7
E	4.4

Table XIII. Change in Signal Strength Level

Material	4G Indoor (dBm)	Outdoor (dBm)	RSS Indoor (fW)	Outdoor (fW)	Percentage Change (%)	Remark
A	-94.6	-92.1	346.7	616.6	43.8	Decrease
B	-93	-92.4	501.2	575.4	12.9	Decrease
C	-94.5	-93.6	354.8	436.5	18.7	Decrease
D	-93	-92.4	501.2	575.4	12.9	Decrease
E	-93.6	-92.6	436.5	549.5	20.6	Decrease

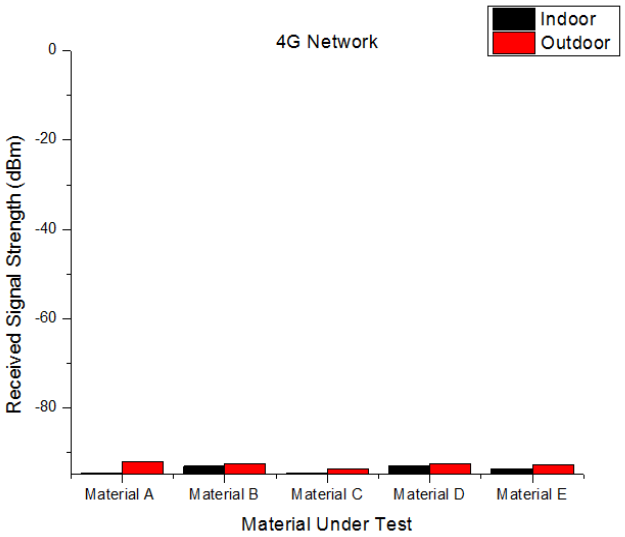


Fig. 3. Mean Value Signal Strength of the Materials (indoor and outdoor).

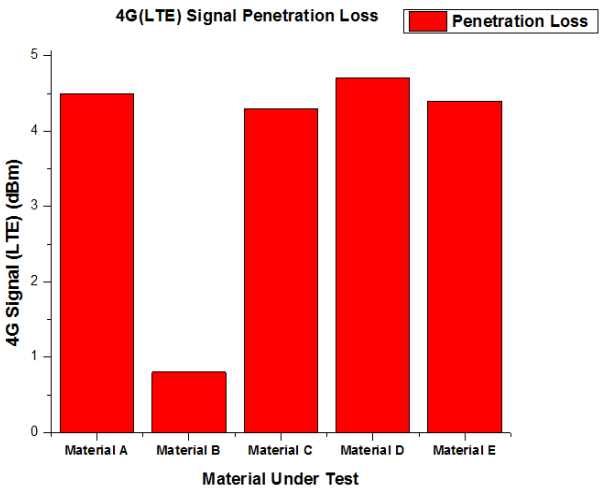


Fig. 4. Materials Penetration Loss

The average value for the RSS which was measured within and outside the materials when subjected to 4G signals is illustrated in Fig. 5.

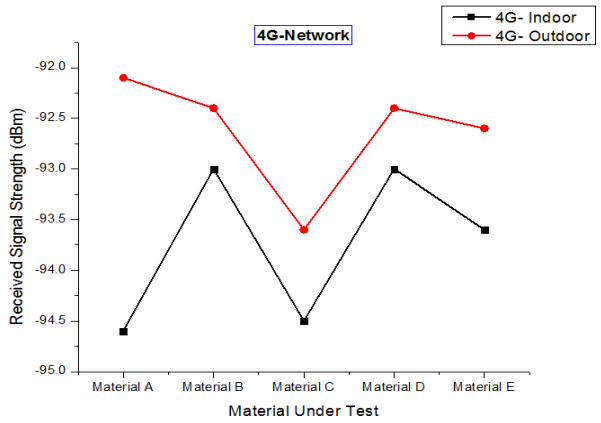


Fig. 5. Indoor and Outdoor RSS Variation

The QoS parameters obtained from Open Nettest in the application interface as presented in Table II to Table XI describe the quality of experience perceived by the users when subjected to different materials for the indoor and outdoor scenario.

As a result, jitter is being considered since it gives substantial variation for both the indoor and the outdoor scenarios. The jitter variation in the selected materials for the 4G signal is demonstrated in Fig. 6.

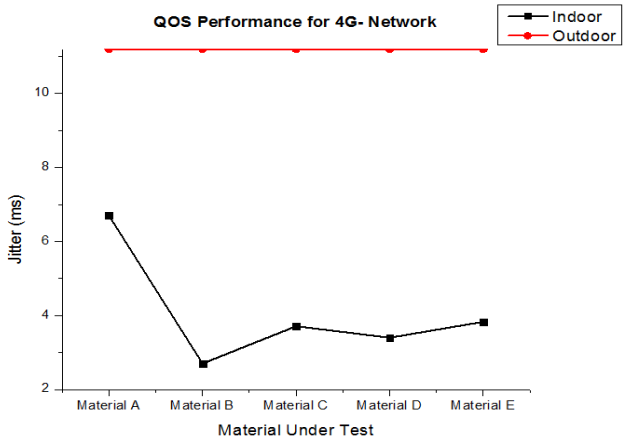


Fig. 6. Jitter Variation in the Materials.

V. CONCLUSION

In conclusion, the results obtained from the surveyed data with the aid of RFST and Open Nettest software showed that the construction materials have significant impact on 4G signal in terms of RSS and QoS. The results of the penetration loss, indoor and outdoor signal strength have been compared. The result from the penetration loss confirms that Material D has the highest penetration loss of 4.7 dBm while Material B has the lowest penetration loss of 0.8 dBm. This, upon benchmarking, conforms with the findings of the related works where it has been illustrated that construction materials affects signal. For the indoor RSS, materials B and D have 12.9 % decrease, Material E has 20.6 % decrease, Material C has 18.7 % decrease, while Material A has 43.8% decrease.

The result from QoS parameter (jitter) have been compared with both outdoor and indoor. It shows that materials B, D, C and E will provide improved experience to the users as a result of their spread. This shows that calculating the material penetration loss accounts for attenuation even as the penetration loss is a function of the material composition.

A limitation of the proposed method is the effect of interference and absorption from human and other materials while measuring during the day or rush hours. It is therefore suggested that surveyed data should be recorded on a 24-hours basis and for several days to obtain higher precision. Another recommendation for future work is the use of spectrum analyzer for measurement of data to circumvent dependence on network service providers and enhance the result accuracy and reliability.

REFERENCES

[1] J. B. Andersen, T. S. Rappaport, and S. Yoshida, “Propagation Measurement and Model for Wireless Communication Channel”, 1995.

[2] C. R. Anderson, T. S. Rappaport, K. Bae, A. Verstak, N. Ramakrishnan, W. H. Tranter, C. A. Shaffer, and L. T. Watson, "In-buiding wideband Multipath characteristics at 2.5GHz and 60GHz," in IEEE Conference, vol. 5, pp. 97-101, 2010.

[3] G. Durgin, T. S. Rappaport, and H. Hu, “Radio Path Loss and Penetration Loss Measurement in and around Homes and Trees at 5.85 GHz, Group:1-4, 2002.

[4] R. Richard, C. Ken, G. Martin, and H. Richard, "Building Materials and Propagation," Department of Signal Science, OFCOM, U.K, Document 2014.

[5] Radio System Installation and Signal Penetration, 2016.

[6] T. S. Rappaport, “Wireless Communications: Principle and Practice”, 2nd ed. Singapore: Pearson Education PTE Limited, 2003.

[7] A. Scott, "Guide to surveying building for Wireless Network", JISC, July 2011.

[8] E. Promise and O. Otasowle, "Determination of GSM Signal Penetration Loss in Some Selected Buildings in River State, Nigeria", Nigerian Journal of Technology (NIJOTECH), vol. 34, no. 3, pp. 609-615, 2015.

[9] S. C. Felicito, and C. D. Jeniffer, "Penetration Loss of Doors and Windows Inside Residence Using ISDB-T Digital Terrestrial Television Signal at 667MHz", in Proceedings of the World Congress on Engineering and Computer Science (WCECS), vol. II, San Francisco, 2011.

[10] E. Promise, P. O. Otasowie, "Investigation of GSM Signal Loss in Multi- Story Building", in International Conference and Exhibition on ICT & Telecommunication, Benin, p. 65, 2016.

[11] V. O. Akpaida, S. I. Uzairue, A. I. Idim, F. I. Anyasi, "Determination of an Outdoor Pathloss Model and Signal Penetration Level in Some Selected Modern Residential and Office Apartment in Ogbomosho Oyo State, Nigeria", Journal of Engineering Research and Reports, vol. 2, no. 1, pp. 1-25, May 2018.