International Journal of Engineering Innovation & Research
Volume 11, Issue 3, ISSN: 2277 – 5668

The Absorption of Millimetre Wave Signal Across Different Building Materials

Adewale Abe[1], Oladunni Juliet Femi-Jemilohun[2*], Bankole Adebanji[3], Emmanuel Taiwo Fasina[4] and Ilesanmi Banjo Oluwafemi[5]
[1,2,3,4,5]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): 25/05/2022

***Abstract* – This work reports the measurements of radio wave propagation inside a modern office environment at ubiquitous 60GHz millimetre wave band. The importance of the research is to investigate the rate of attenuation of wireless signal in an office environment by the furniture and other building materials that a modern office comprises off. As some of the office layout scan serve as obstructions to line of sight propagation required by the wireless propagation for the frequency operation in the millimetre wave band, the results show appreciable propagation attenuation over the 60GHz IEEE 802.11ad wireless link. This will no small way degrade the quality of signal transmission during a real time application of this link by end users desiring a seamless transmission in office settings.**

***Keywords* – Building Materials, Throughput, Millimetre Wave Spectrum, Wireless Link, Real Time Application.**

I. INTRODUCTION

The random nature of wireless link makes them susceptible to problems such as frequent link failures, co-channel interference, latency and congestion which degrade system performance. Delivering good quality video over wireless link and at the same time maintaining best end-to-end performance entails considering factors which can mitigates against such accomplishment such as resource allocation, bottlenecks, overheads, compression techniques, in other to fashioned out a well-tailored, scalable and robust design. The unfavourable propagation characteristics exhibited at this band and increased free space path loss as a result of several reflective paths over wide channel bandwidths can be overcome and often seems advantageous [1]. In the last few years, researchers have carried out works aimed to develop telecommunication systems for commercial use [2] [3] [4] [5]. There is more spectrums available in the 60 GHz than at 2.4 and 5 GHz bands, which permits broader channels (2.16 GHz wide) to support very fast data rates of about 7 Gbps by employing modulation techniques of lesser power, suitable for indoor connectivity to cater for requested multimedia applications [6]. Its small wavelengths of approximately 5mm allows for the use of compact and competitive antenna arrays to aid beam-forming. The major challenges facing transmission at 60 GHz mm-wave WLAN are: high attenuation of 68 dB at 1m and 91 dB beyond 10m distance, when propagating through obstacles, and oxygen absorption. Through spectral reuse at 60 GHz, the 802.11ad would significantly improve the quality of the wireless link, and increased data rate, reduce the demands on the congested 2.4 GHz and 5 GHz. The large unlicensed and unutilized bandwidth of at least 5 GHz present around 60 GHz millimetre wave make wireless communications promising and seems very suitable because of its ultra-high speed within a room in applications requiring higher bandwidths as in uncompressed high video transmission, wireless display, gigabit file transfer, wireless docking. The driving impetus for new technology that supplements 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 [6] to produce multi-gigabit speed to support advanced applications. The small physical size of 60 GHz antenna makes commercialization of phased array antenna system feasible. A pair of devices (transmitter and receiver) operating on this frequency bands can employ beam-forming technique to train their antenna systems for peak transmission dependability. This ability maximizes radio signal strength and permit resilient communication at distance greater than 10m. The short range inherent in 60GHz signal propagation is the driving force behind the experimental work presented in this paper.

II. RELATED WORK

The demand for higher throughput in digital wireless communications will always increase. To keep up with exponential growth in data traffic when several users share same physical resources requires upgrades in air interface capacity and the use of new spectrum. The Wireless Gigabit Alliance (WiGig) initiated the development and promoted the adoption of multi-gigabit per second speed wireless communications technology which uses the unlicensed spectrum around 60 GHz band [7]. There is more spectrum available in the 60 GHz than at 2.4 and 5 GHz bands, which permits broader channels (2.16 GHz wide) to support very fast data rates of about 7 Gbps by employing modulation techniques of lesser power, suitable for indoor connectivity to cater for requested multimedia applications [6]. Its small wavelengths of approximately 5mm allows for the use of compact and competitive antenna arrays to aid beam-forming. Transmission at 60GHz band is short range and as such, the authors carried out experimental work on the absorption of this very high frequency signal by certain materials. This is necessary such that the seemingly disadvantage of propagation over short distance is not adversely affected by the absorption rate and or coefficient of the materials used in this work. The inherent limitation in 60 GHz propagation is that its attenuation increased with distance. IEEE 802.11ad devices have very short range of 10 meters, coupled with attenuation of 22 dB in comparison to the 5 GHz band as predicted by the Friis transmission equation. On the other hand, oxygen absorption has no major adverse effect over short range distances, although it increased at 60 GHz [8]. Furthermore, 60 GHz communication displayed quasi-optical propagation characteristics and as such, the received signal is dominated by the line of sight (LOS) path and high order reflections from materials of high reflecting properties, such as metallic surfaces which permits non-line-of sight (NLOS) communication [9]. Thus, 60 GHz communication is more suitable to in-door environments where sufficient reflectors are present. The study [10] enumerated the design assumption coming from the mm-Wave propagation characteristics and related adaptation to the 802.11 architecture but did not include absorption of 60GHz signals. The work [11] carried out the assessment of RF radiation in the far field in a selected mobile based station sites. The results indicates that the specific absorption rate (SAR) are quite lower than the limit by the international commission on non-ionizing radiation protection (ICNIRP). The authors [12] used the dielectric loss property of carbon black to study the reflection losses by employing arched testing method in the frequency range from 2GHz to 18 GHz. There were improved absorption properties at high frequency as the work suggested. Another work [13] only reviews the extent and future potentials of cement based EMI shielding and wave absorbing building materials. The authors measured the shielding effectiveness and reflection in the range of high frequencies from 1 GHz to 9 GHz by step of 0.2 GHz. In the work, the object of investigation is a brick wall with a thickness of 0.25 m and the surface area of 2x2 m [14]. The work [15] majorly is on characterization of 60-GHz channels in space and time delay. This output shows vital empirical values for 60-GHz system design and a fundamental basis for ray tracing development and verification, it equally propose a better understanding of the radio wave propagation at millimetre-wave frequencies. The effect of signal absorption by building materials was conducted by [16], but the author's investigation was based on millimetre wave propagation at frequency spectrum of 24GHz. Because of the recent awareness and limited use of 60GHz, and compatible equipments available, fewer researchers are investigating how to harness the ubiquitous unlicensed spectrum. This work is unique in that the authors carried out experimental evaluation of 60GHz transmission and absorption over IEEE 802.ad devices in real life scenarios.

II. MATERIALS AND METHODS

This section focuses on evaluating the level of absorption of wireless signal by different material objects at 60GHz. These materials serve as obstacles between the transmitter and 802.11ad device. These parathion between he transmitter and the 802.11ad A. Pisdmetres, measured from 1mup to18m as in Fig. 1.

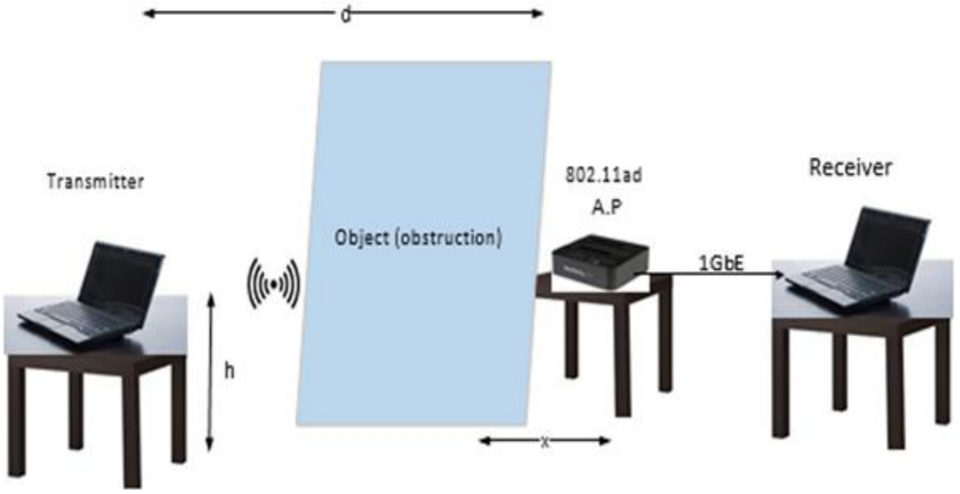


Fig. 1. Experimental set-up.

To ensure that the beam from the dock did not jump the obstacles, the dock was placed at distance x m (0.5) close to the objects. The transmitter, the A.P, and the receiver were placed at height 0.65m respectively. The experiment location was the forth floor of the network building at University of Essex, UK. The experiment was conducted on weekend when human traffic on campus was minimum for accurate readings.

III. RESULTS AND DISCUSSION

Table 1 shows the throughput of each material in MBits/s. LOS throughput is 906. 836 MBits/s. Figure 4 and 5 are snapshot of average throughput of each material used in the experimental work. The snapshots also indicates thread real-time (s), throughput (KB/s), average bytes per completion, total bytes (MEG), average frame size, total buffers, throughput (Buffers/s), packet sent, packet received, total retransmit, total errors, average cycles/bytes. It can be deduced from fig 2 that materials made of perspex, hardwood and glass permits high signal penetration at 60GHz band when comparing their throughput to that of LOS (906.826 MBits/s), which is 903.836 Mbit/s for perspex, 896.956 MBits/s for hardwood and 907.311 MBits/s for glass. On the other hand, fig 3 presents average throughput of 405.050 MBits/s for FR4 PCB, 410.780 MBits/s for steel1 and 399.969 MBits /s for steel2. This is an indication that FR4 PCB absorbed 57.27%, steel1 absorbed 56.70% while steel2 absorbed 57.81% of the transmitted signals. This is known from table 1 from which the maximum data rates measured in real-time within the corridors between the transmitter and the receiver is 948 MBits/s from maximum link speed of 1 Gbits/s. From figure 3, steel1 and steel2 have same throughput of 400 Mbps at 1m and

380 Mbps at 2.8m respectively. Steel 1 maintained stable connection between 3m and 4m distance where its bitrate was 390 Mbps and from this point suffers abrupt signal degradation up to 5.1m distance. This caused reduction of its bitrate to 160 Mbps at 5.1m. Steel2 bitrate continually exhibit downward trend from 1m until its 0 Mbps at 5m. This downward trend is similar to FR4 PCB at a distance of 1m which was 630 Mbps until its bitrate reached 180 Mbps at 4m before ascending linearly upward to 385 Mbps at 5.2m. It maintained this bitrate until at 6.1m and then suddenly experienced high propagation loss and thus the bitrate decreased faster and reached 0 Mbps at 7m.

On the other hand, the high reflective property of mirror can be seen in that its throughput was much higher between 1m and 4.5m. At this distances, maximum throughput was about 900 Mbps and minimum was 830 Mbps. Beyond 4.5m, its bitrate drops sharply to 0 Mbps. Interestingly, Figs 2 and 3 show that some of these materials have same throughput at some distances as revealed in table 1 for steel 1 and 2. Also, FR4 PCB and steel 2 have same bitrate. The mirror and FR4 PCB bitrate is the same at 4.8m.

Table 1. Average throughput of the materials in Mbps and their thickness.

Objects	Average Throughput (Mbps)	Thickness (m)
Perspex	903.988	4.5
Hardwood	896.956	2.5
FR4 PCB	485.050	2.3
Steel 1	410.788	0.5
Mirror	893.998	2.0
Steel 2	399.969	2.0
Plate Glass	907.311	6.0

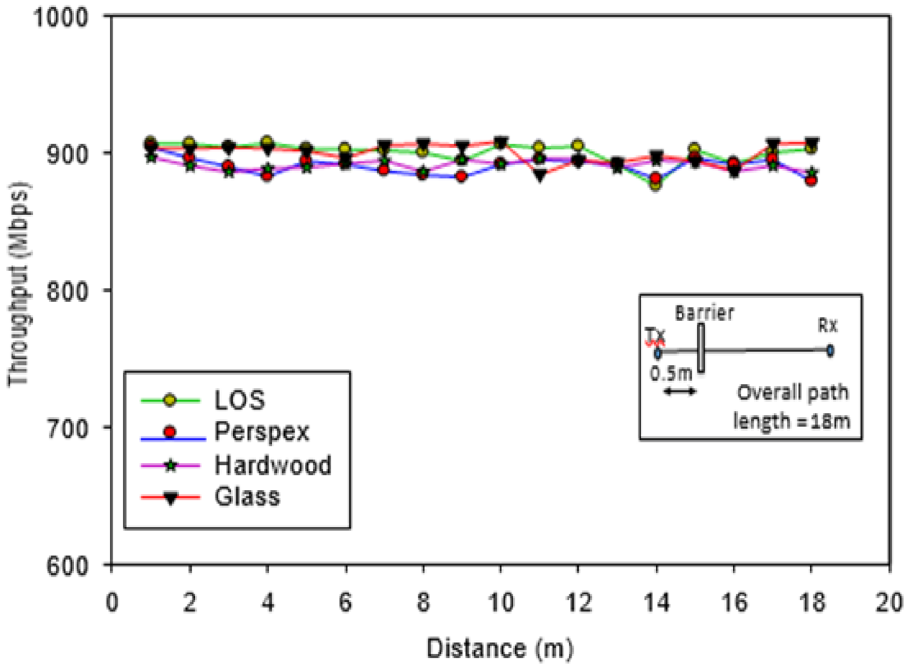


Fig. 2. Materials absorption at 60 GHz.

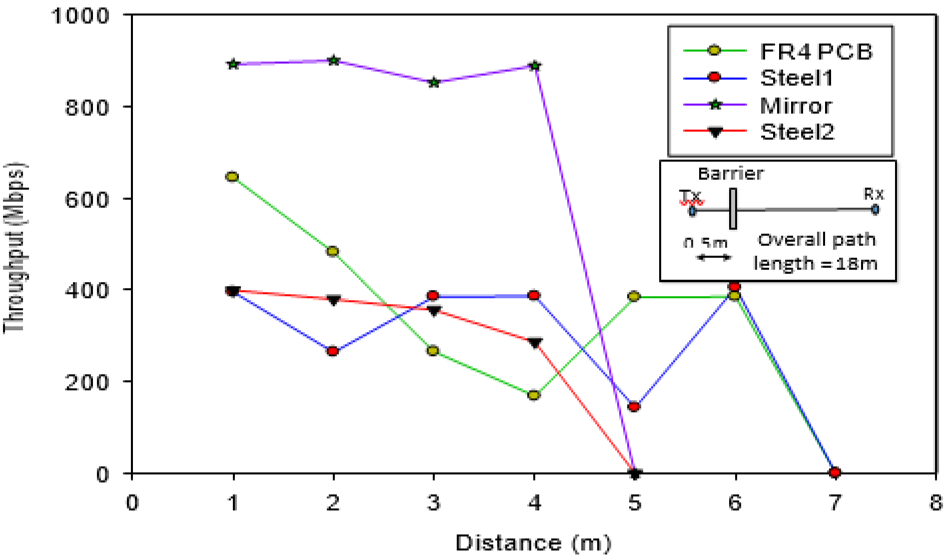
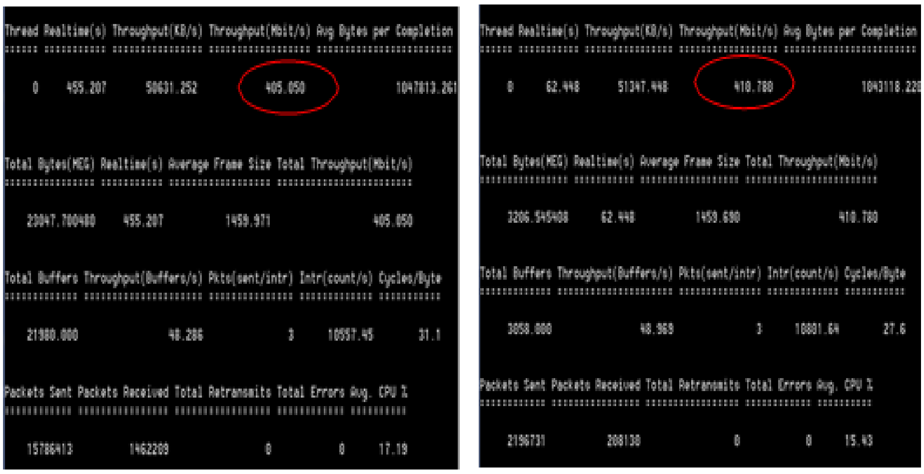


Fig. 3. Materials absorption at 60 GHz.

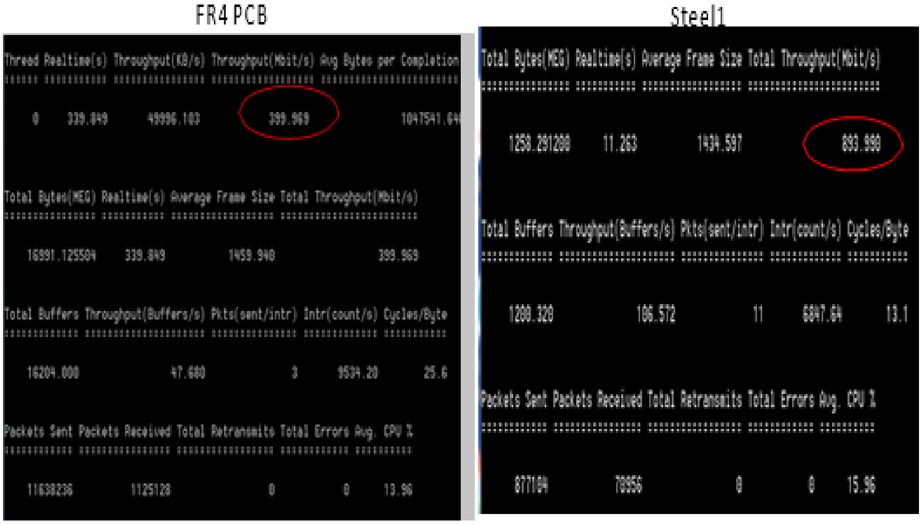


```
Thread Realtime(s) Throughput(KB/s) Throughput(Mbit/s) Avg Bytes per Completion
====== ========== ================ ================= =======================

   0    455.207      50631.252          405.050              1047813.261


Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ ========== ================== ========================

  23047.700480    455.207         1459.971                     405.050


Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ==========

  21980.000               48.286                3     10557.45      31.1


Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

  15786413        1462203                0           0     17.19
```

FR4 PCB

```
Thread Realtime(s) Throughput(KB/s) Throughput(Mbit/s) Avg Bytes per Completion
====== ========== ================ ================= =======================

   0    62.448      51347.448           410.780              1043118.220


Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ ========== ================== ========================

   3206.545408    62.448          1459.690                     410.780


Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ==========

   3058.000               48.969                3     10881.64      27.6


Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

   2196731         208130                0           0     15.43
```

Steel1



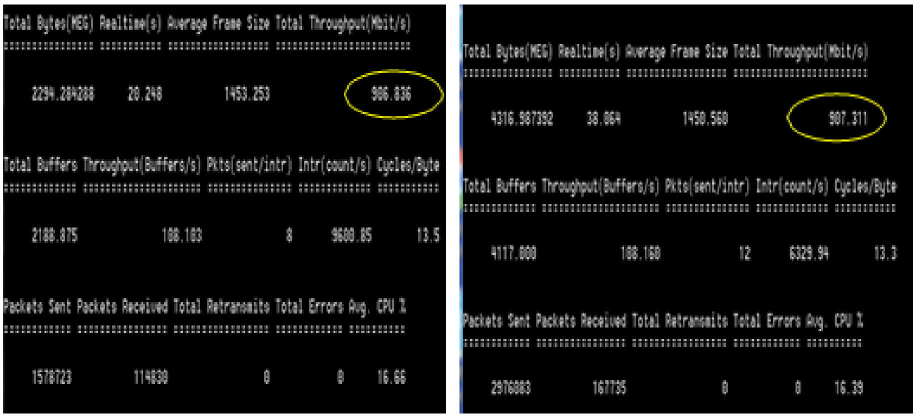
```
Thread Realtime(s) Throughput(KB/s) Throughput(Mbit/s) Avg Bytes per Completion
====== ========== ================ ================= =======================

   0    339.849      49996.103          399.969              1047541.04


Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ ========== ================== ========================

  16991.125504    339.849         1459.940                     399.969


Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ==========

  16204.000               47.680                3      9534.20      25.6


Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

  11638236        1125128                0           0     13.96
```

```
Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ ========== ================== ========================

   1258.291200    11.263         1434.597                     893.990


Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ==========

   1208.320              106.572               11      6847.64      13.1


Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

    877104          78956                0           0     15.96
```

Steel2

Mirror

Fig. 4. Throughput of FR4 PCB, steel1, steel2 and mirror.

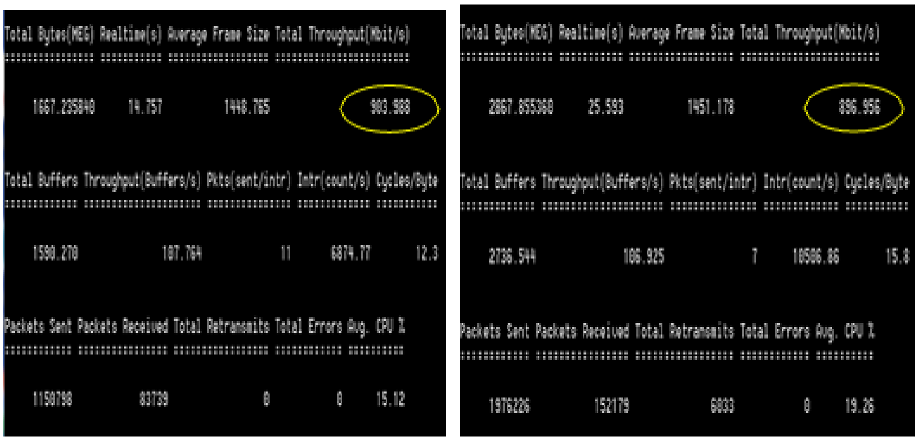


```
Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ =========== ================== ========================

   2294.284288     20.248          1453.253                    906.836

Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ===========

   2188.875              108.103               8       9600.85         13.5

Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

   1578723         114838                 0            0     16.66
```

LOS

```
Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ =========== ================== ========================

   4216.987392     38.064          1450.560                    907.311

Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ===========

   4117.000              108.160              12       6329.94         13.3

Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

   2976083         167735                 0            0     16.39
```

Glass



```
Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ =========== ================== ========================

   1667.235840     14.757          1448.765                    903.988

Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ===========

   1590.270              107.764              11       6874.77         12.3

Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

   1150798          83739                 0            0     15.12
```

Perspex

```
Total Bytes(MEG) Realtime(s) Average Frame Size Total Throughput(Mbit/s)
================ =========== ================== ========================

   2867.855360     25.593          1451.178                    896.956

Total Buffers Throughput(Buffers/s) Pkts(sent/intr) Intr(count/s) Cycles/Byte
============= ===================== =============== ============= ===========

   2736.544              106.925               7      10586.86         15.8

Packets Sent Packets Received Total Retransmits Total Errors Avg. CPU %
============ ================ ================= ============ =========

   1976226         152179              6033            0     19.26
```

Hardwood

Fig. 5. Throughput of FR4 PCB, steel1, steel2 and mirror.

IV. CONCLUSION

This work investigated the effect of building material such as perspex, mirror and wood on wireless propagation at the high spectrum. In summary, perspex, hardwood and glass are recommended for use in buildings to allow maximum signal reception which will lead to good Qos when transmission over 60GHz. Thus permeability and resistivity of these materials is crucial in the design of building to aid easy wireless transmission at 60 GHz. The results of this work thus proposes the use of more pair of devices, that is transmitter and receiver operating on this frequency bands to employ beam forming technique to train their antenna systems for peak transmission dependability. The antenna penetrating power should also be made more powerful as this capability will maximize radio signal strength and permit resilient communication at distance greater than 10m synonymous to 60GHz transmission.

ACKNOWLEDGEMENT

This work is sponsored by the Federal Government of Nigeria through the Tertiary Education Trust Fund (TETFUND) scheme. The technical support and expertise of Prof S.D Walker, the Head of Access Network Group, University of Essex in the course of this research work is highly appreciated.

REFERENCES

[1] T.S. Rappaport, J.N. Murdock, and F. Gutierrez, “State of the art in 60-ghz integrated circuits and systems for wireless communications," *Proceedings of the IEEE*, 2011 pp. 1390-1436.

[2] ECMA, "Standard ecma-387: High rate 60ghz phy, mac and pals," tech. rep., ECMA International, 2nd Edition, December 2010.
[3] C.J. Hansen, "Wigig: multi-gigabit wireless communications in the 60 ghz band, "Wireless Communications, IEEE, 2011 pp.6-7.
[4] T. Baykas, C.-S. Sum, Z. Lan, J. Wang, M.A. Rahman, H. Harada, and S. Kato, "Ieee 802.15. 3c: the first ieee wireless standard for data rates over 1 gb/s," Communications Magazine, IEEE, 2011 pp. 114-121.
[5] P. Smulders, "Exploiting the 60 ghz band for local wireless multimedia access: prospects and future directions," Communications Magazine, IEEE, 2002 pp. 140-147.
[6] W. Alliance, "Wigig R and the future of seamless connectivity," 2013.
[7] S. Karl, "Wi-fi alliance and wireless gigabit alliance finalize unification," (Press release) Retrieved November, 2013.
[8] R. Wilson, "Propagation losses through common building materials 2.4 ghz vs 5 ghz," Magis Networks Inc.: San Diego, CA, USA, 2002.
[9] H. Xu, V. Kukshya and T. Rappaport, "Spatial and Temporal Characteristics of 60-GHz Indoor Channels", IEEE Journal.
[10] Thomas Nitsche, Carlos Cordeiro, Adriana Flores, Edward W. Knightly, Eldad Perahia, and Joerg C. Widmer., "IEEE 802.11ad: Directional 60 GHz Communication for Multi-Gbps Wi-Fi.
[11] Joseph isabona, Divine Osamiromwen Ojuh, "Experimental assessment of specific absorption rate using measured electric field strength in Benson Idahosa University and environs" American Journal of Modern Physics, pp 92-96.
[12] Zhang, Y.F., Hao, W.J., Duan, Y.P., Liu, S.H., "Electromagnetic wave absorption properties of cement filled with carbon black" Applied mechanics and materials, 2014. pp 2431-2434.
[13] Hongtao Guan, Shunhua Liu, Yuping Duan, Ji Cheng., Cement based electromagnetic shielding and absorbing materials. cement and concrete composites, 2006, pp 468-474.
[14] lMarek Pavlík, Iraida Kolcunová, Lukas Lison, "Measuring the shielding effectiveness and reflection of electromagnetic field of building material" IEEE, 2015.
[15] Hao Xu, Vikas Kukshya, and Theodore S. Rappaport, "Spatial and Temporal Characteristics of 60-GHz Indoor Channels" IEEE Journal On Selected Areas In Communications, 2002
[16] Femi-Jemilohun O.J". Effects of building material on real time application in radio wave at Millimetre Wave Spectrum" International Journal for Research in Applied Science & Engineering Technology, 2019, 2623-2628.

AUTHOR'S PROFILE

First Author
Adewale Abe, received the B.Eng.degree in theElectrical 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) from University of Essex, UK in 2018. His researh interest are Electronic and Telecommunication Engineering, Millimeter-Wave propagation, 4k Video transmission . He is a resgistered 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 (COREN), 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 researh interest are Renewable energy, Power system engineering, Hybrid, Small hydro and optimization.He is a resgistered COREN Engineer and a member of Nigerian Society of Engineers (MNSE). He is currently a Senior lecturer in theElectrical and Electronic Engineering department of Ekiti State University, Ado-Ekiti, Nigeria.

Fourth 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, localised energy systems, smartgrid, Electric vehicles, deregulation, and electricity transmission pricing.

Fifth Author
Ilesanmi B. Oluwafemi, received the B.Eng degree in Electrical and Electronic Engineering from University of Ado Ekiti, Nigeria in 2000. He obtained the Master of Engineering degree in Electronic and Telecommunication from University of Benin, Nigeria in 2005 and PhD degree in Electronic Engineering at the School of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, South Africa in 2012. He is currently an Associate Professor in the Department of Electrical and Electronic Engineering, Ekiti State University, Nigeria and the Research leader of the Center for research in Electrical Communication (CRECO). His research interests are in the area of signal propagation, indoor power line communication, Signal Processing, Wireless sensor Network, wireless communication including space-time coding, channel coding, MIMO and OFDM systems.