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Empirical Investigation of Indoor/NLOS Propagation at Millimeter Wave Bands For Gigabits Throughput Realization: 24 And 60ghz Links

Femi-Jemilohun Oladunni .Juliet, Walker Stuart.
School Of Computer Science and Electronic Engineering, University of Essex, Colchester, Essex, United Kingdom

ABSTRACT ***:*** *The growth in the communication industry demands a high bandwidth capacity to cope with the multimedia application services. The lower frequency bands allocated for communication, apart from being congested, is also incapable of the gigabits throughput delivery needed for the various applications. Therefore, it is highly imperative to engage the millimeter wave frequency bands to provide the adequate frequency spectrum. The peculiarities of the millimeter wave propagation are challenges to achieve this goal. This work conducted empirical measurements of the indoor propagation performances of 24 and 60GHz frequency bands. The results show that 24GHz band performs better in NLOS propagation than 60GHz hence, WLAN with gigabits throughputs can be deployed within offices in a modern building using the 24GHz Ubiquity Air fiber ptp links.*

Keywords **-***Ubiquity, AirFibre, point-to point*

I. INTRODUCTION

The telecommunication industry has experienced an explosive growth pressure in the recent decades. This has led to demand for higher data rates throughputfor wireless multimedia applications, hence, a major tilt in the wireless communication sector to engage the higher frequency bands especially the millimeter waves bands, for indoor propagation. This is as a result of the huge availability of, coupled with less congested bandwidths, that permits dense frequency re-use opportunity for effective and optimal spectrum utilization for present and future mobile multimedia application purposes . These bands withtheir peculiar propagation characteristics of atmospheric absorption and free space path losses, notwithstanding, can support high throughput rate to the other of gigabits per seconds (Gbps) using their wide spectral allocations to provide huge spectral efficiency wireless network systems. [1].The ever increasing supply of, and demand for, broadband multimedia to match up with the ever increasing capacity of wireless networks, has led to wireless transfer demand that is far beyond what the current bands in the ISM and UNII can accommodate The high data rates intended for 4G infrastructures will require the use of unlicensed spectrum with sufficient bandwidth to accommodate such huge capacities [2]. A way out is to resort to the millimeter wave bands. Millimeter wave bands correspond to the radio spectrum that span between 30GHz- 300GHz with wavelength between 10mm-1mm. Also, the limitations and congestion matters in ISM and UNNI frequency bands, has necessitated the attempt by the communication industry to explore the unlicensed frequencies band around the millimeter wave band. The 60 GHz frequency band presents a very large bandwidth that has been allocated to mobile communication.[3, 4]. Since the quest for high speed and large channel capacity, digital data rates for multimedia wireless communication cannot be realized in the frequency of lower bands, millimeter wave has come to the lime light of research community as well as industrial sector. As the major option for short range high speed communication system that matches the task of providing a wide spectrum bandwidth required by multimedia consumer oriented applications such as uncompressed video streaming, and kiosk flash downloading services. All of these require multi gigabit throughput that can only be got in 60GHz, hence it is most importantly now been used for short distance radars and indoor communications.The directional antenna technology embedded in these frequency bands enables the wireless network system to attain higher bit rates and improve spectrum re-use, likewise the narrow beams which characterize these bands helps to attenuate the effects of multipath propagation[5]. A study and comparison of indoor propagation property at 24GHz and 60GHz is conducted in this work.

II. REVIEWS OF PREVIOUS WORKS

A numerous investigations of indoor propagation have been carried out on the lower frequency spectrum and micro wave bands, but there are few authors submissions on the propagation features of Millimeter frequency spectrum especially in the indoor scenarios, as the multimedia applications continues to increase in geometrical rate as the days go by, the necessity to engage themillimeterin the indoor propagation application to cope with the demand for gigabit throughput is highly needed for the real time applications .Hence investigation into Millimeterindoor propagation is a welcoming venture at this point in time in communication industry.

[6] reported in their work the indoor propagation factors at 17 and 60 GHz, focusing on the narrow beamwidth of the channels for a requirement to achieve efficient system network in relation to area coverage and frequency re-use. [7]worked on the simulation and analysis of 60GHz millimeter wave indoor propagation characteristic based on shooting and bounding ray tracing/image to determine a foundational indoor coverage forMillimeter communication system., however, the simulated environment was non-ideal. In like manner[8] reported the results of their investigation on the indoor Millimeter channel at 6oGhz in application to perspective WLAN systems, their work demonstrated the need for a steerable directional antenna for LOS or low-order NLOS reflected path for effective results in a typical indoor scenario, while polarization mismatch between the antenna and propagation channel may incur up to 10-20 dB signal degradation.[9]investigated the indoor propagation measurements at 60GHz in a modern office and by a ray tracing simulations to determine the effects of antenna directivity and polarization on indoor multipath propagation characteristics of the channel. [10] in their work used combined E/H-plane ray tracing method to model indoor wireless channel from 2.4 to 24GHz, they were able to predict loss for both LOS and NLOS paths as well as RMS spread for LOS. This work differs by investigating the indoor characteristics of Millimeter wave spectrum with emphasis on 24 and 60 GHz indoor propagation comparison in realizing gigabits throughputs capacity in wireless systems. By design and for the fact that Millimeter has very small wavelengths, connections on these bands require perfect LoS for strong and reliable capacity, hence obstructions on the path of the transmission such as trees, buildings, windows, will significantly impact link performance, it is therefore expected that these bands will perform worse in the indoor propagation where there are lots of obstruction to absorb the signal transmission preventing LoS environment. Fortunately, the results of the empirical investigation proved otherwise.

III. BACKGROUND STUDY

3.1 60GHz Phased Array Transceiver:

This is implemented in standard digital CMOS and packaged with embedded antenna array, capable of robust 10m non-line of sight communication. The transceiver pair supports the WirelessHD and draft 802.11ad (WiGig) standards at maximum data rates of 7.14 GB/s and 6.7 GB/s, respectively. The computed array factor of the transceiver pair together with the WirelessHD chip in operation link performs a dynamic beam search to avoid interferer blocking the path of the transmission system, finding a new optimal path for the transmission through the electronically steerable phased array. This process takes less than 1ms. . The source uses 32 transmitting elements to transmit to 32 receiver elements of the sink. While on the reverse lower data rate direction, the sink uses 8 transmitting element to transmit to 4 receiver elements on the source [11].

3.2 24GHz UNLICENSED BAND:

24 GHz license free band is replacing the 2.4 and 5GHz bands point-to-point links where interference is substantially reducing data throughput and sensitivity. 24GHz is in the millimeter wave band and has a very low noise floor because this band is not heavily laden with millions of devices. 24 GHz radio signals do not go as far as the 2.4 and 5 GHz bands because there is more atmospheric attenuation at this frequency and higher attenuation due to rain. Radio waves are more directional; has a narrower beam of energy. This means that signals at 24 GHz do not bounce around like the signals at 2.4 and 5 GHz to create a noisy environment. Additionally, because radios at these frequencies have traditionally been very costly and bulky, few have been deployed. This means that 24 GHz is an interference free frequency and will not suffer the degradation and difficulties of the noisy 2.4 and 5 GHz frequency bands. One of the best advantages of the 24 GHz band is its inherent security. Virtually all 24 GHz operation uses either horn or parabolic dish antennas [12] [13].

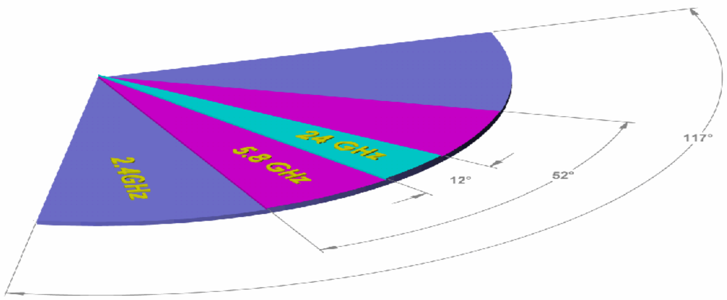


Figure.1: comparison of Beam Widths of microwave and millimeter wave bands

3.3 UBIQUITY AIRFIBER 24 GHz POINT-TO-POINT RADIO ADVANCED ANTENNA SYSTEM:

Ubiquiti air Fiber 24 GHz Point-to-Point radios, a truly revolutionary 24 GHz Point-to-Point radio from Ubiquiti Networks. Air Fiber delivers revolutionary performance of 1.4+ Gbps, aggregate throughput and 13+ km in range. Packets per second greater than 1 Million with EIRP of approximately 33dBm, Channel bandwidth of 100MHz ,operating channel 24.1 and 24.2GHz, Modulation of 64QAM MIMO, 16QAM MIMO, QPSK MIMO, and SISO. It has a gains of 33dBi, beamwidth less than 3.5 degrees. The Ubiquiti air Fiber features a dual-independent 2x2 MIMO 24GHz hi-gain reflector antenna system. The air Fiber can operate in both FDD (Frequency Division Duplex) and HDD (Hybrid Division Duplex) modes, resulting in unparalleled speed and spectral efficiency in the 24GHz worldwide license-free band. Ubiquitin's Innerfeed and AirMax (MIMO TDMA Protocol) technologies are designed to create a simple, yet extremely powerful and robust wireless unit, which is capable of 100+Mbps real Point-to-Point throughput up to a 13km+ range [14].

3.4 WAVE REFLECTION AND TRANSMISSION AT A PLANE INTERFACE:

When a vertical or parallel polarized wave hits an interface, the wave divides into two, reflected and transmitted parts. If the plane wave incident on the interface at an angle θi to the normal, electric and magnetic fields can be defined as follows according to [6];

$$E_i = \hat{a}E_o e^{-j\beta_1(x\sin\theta_i + z\cos\theta_i)} \quad (1)$$

$$H_i = (\hat{a}_z \sin\theta_i - \hat{a}_x \cos\theta_i)\frac{E_o}{\mu_1} e^{-j\beta_1(x\sin\theta_i + z\cos\theta_i)} \quad (2)$$

In a similar manner, the reflected fields travelling at an angle θ_r to the normal can be defined as follows:

$$E_r = \hat{a}_y R_s E_o e^{-j\beta_1(x\sin\theta_r - z\cos\theta_r)} \quad (3)$$

$$H_r = (\hat{a}_x \cos\theta_r + \hat{a}_z \sin\theta_r)\frac{R_s E_o}{\mu_1} e^{-j\beta_1(x\sin\theta_r - z\cos\theta_r)} \quad (4)$$

And the transmitted fields can be written as:

$$E_t = \hat{a}_y T_s E_o e^{-j\beta_2(x\sin\theta_t + z\cos\theta_t)} \quad (5)$$

$$H_t = (\hat{a}_z \sin\theta_t - \hat{a}_x \cos\theta_t)\frac{R_s E_o}{\mu_1} e^{-j\beta_1(x\sin\theta_t - z\cos\theta_t)} \quad (6)$$

From (1) and (6) we can write

$$e^{-j\beta_1 x\sin\theta_i + R_s e^{-j\beta_1 x\sin\theta_r}} = T_s e^{-j\beta_2 x\sin\theta_t} \quad (7)$$

Hence,

$$\frac{1}{\mu_1}(-\cos\theta_i\, e^{-j\beta_1 x\sin\theta_i} + R_s \cos\theta_r e^{-j\beta_1 x\sin\theta_r}) \quad (8)$$

From Snell's law,

$$\theta_r = \theta_i \quad (9)$$

And

$$\beta_1 \sin\theta_i = \beta_2 \sin\theta_t \quad (10)$$

$$1 + R_s = T_s \quad (11)$$

$$\frac{\cos\theta_i}{\mu_1}(-1 + R_s) = -\frac{\cos\theta_t}{\mu_2} T_s \quad (12)$$

Solving the above yields,

$$R_{FS} = \frac{E_{rs}}{E_{is}} = \frac{\mu_2\cos\theta_i - \mu_1\cos\theta_t}{\mu_2\cos\theta_i + \mu_2\cos\theta_t} \quad (13)$$

$$T_{FS} = \frac{E_{rs}}{E_{is}} = \frac{2\mu_2\cos\theta_i}{\mu_2\cos\theta_i + \mu_1\cos\theta_t} \quad (14)$$

$$R_{FP} = \frac{\mu_1\cos\theta_i + \mu_2\cos\theta_t}{\mu_1\cos\theta_i + \mu_2\cos\theta_t} \quad (15)$$

$$T_{FP} = \frac{2\mu_2\cos\theta_i}{\mu_1\cos\theta_i + \mu_2\cos\theta_t} \quad (16)$$

The reflection and transmission coefficients of a smooth homogeneous dielectric plate are given as:

$$R = \frac{1 - e^{-j2\delta}}{1 - R^2{}_{F_{SP}} e^{-j2\delta}} R_{F_{SP}} \quad (17)$$

And

$$T = \frac{1-\left(R^2{}_{F_{SP}}\right)-e^{-j(\delta-k_o d)}}{1-R^2{}_{F_{SP}}e^{-j2\delta}} \tag{18}$$

Where $\delta = \frac{2\pi d}{\lambda}\sqrt{n^2 - sin^2\theta_i}$, $k_o = \frac{2\pi}{\lambda}$, λ is the wavelength in the free space,

d is the thickness of sample plate, n= με is the complex refractive index of the sample plate and ε is the permittivity in farads per meter.

3.4. INCIDENCE ANGLES ON ROUGH SURFACE ESTIMATION:

(13) and (15) solve the specular reflection from smooth surfaces; the scattering of the impinging energy by a rough surface causes an attenuation in the reflected parts of the transmitted signal. Rayleigh criterion helps to determine the roughness of the materials. The following equations define the path and phase difference between the two rays.

Where$\delta = \frac{2\pi d}{\lambda}\sqrt{n^2 - sin^2\theta_i}$, $k_o = \frac{2\pi}{\lambda}$, λ is the wavelength in the free space,

$$\Delta l = 2h_c \cos\theta_i \tag{19}$$

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta l \tag{20}$$

When$\Delta\varphi = \pi$, then the surface is very rough, $\Delta\varphi = 0$, means the surface is smooth and $\Delta\varphi = \frac{\pi}{2}$ gives intermediate situation

Therefore,

$$h_c = \frac{3X10^8}{8f\cos\theta_i} \tag{21}$$

h_c<$\Delta\varphi$ gives a rough surface otherwise it is smooth and in a perfectly smooth surface, h_c is very small causing the two rays to be almost at the same phase.

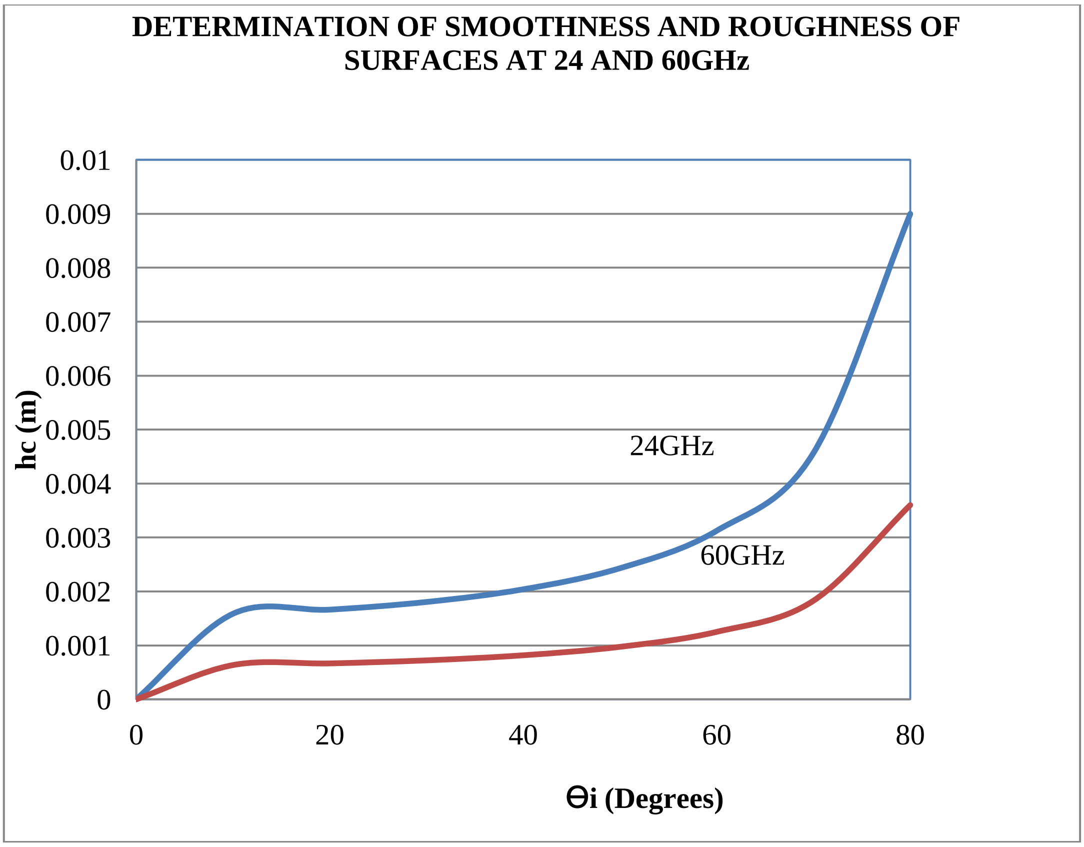


Figure.2: Comparison of hc plotted against the angle of incidence θ_i for 24GHz and 60GHz

IV. EXPERIMENTAL SETUP

An empirical approach is adopted in this work to investigate real time applications of millimeter wave bands in indoor wireless networks systems. The experimental setups are shown in figures below:

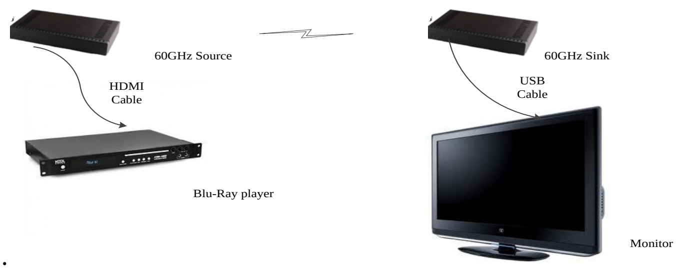


Fig 3:60GHz Transmission Measurement set up

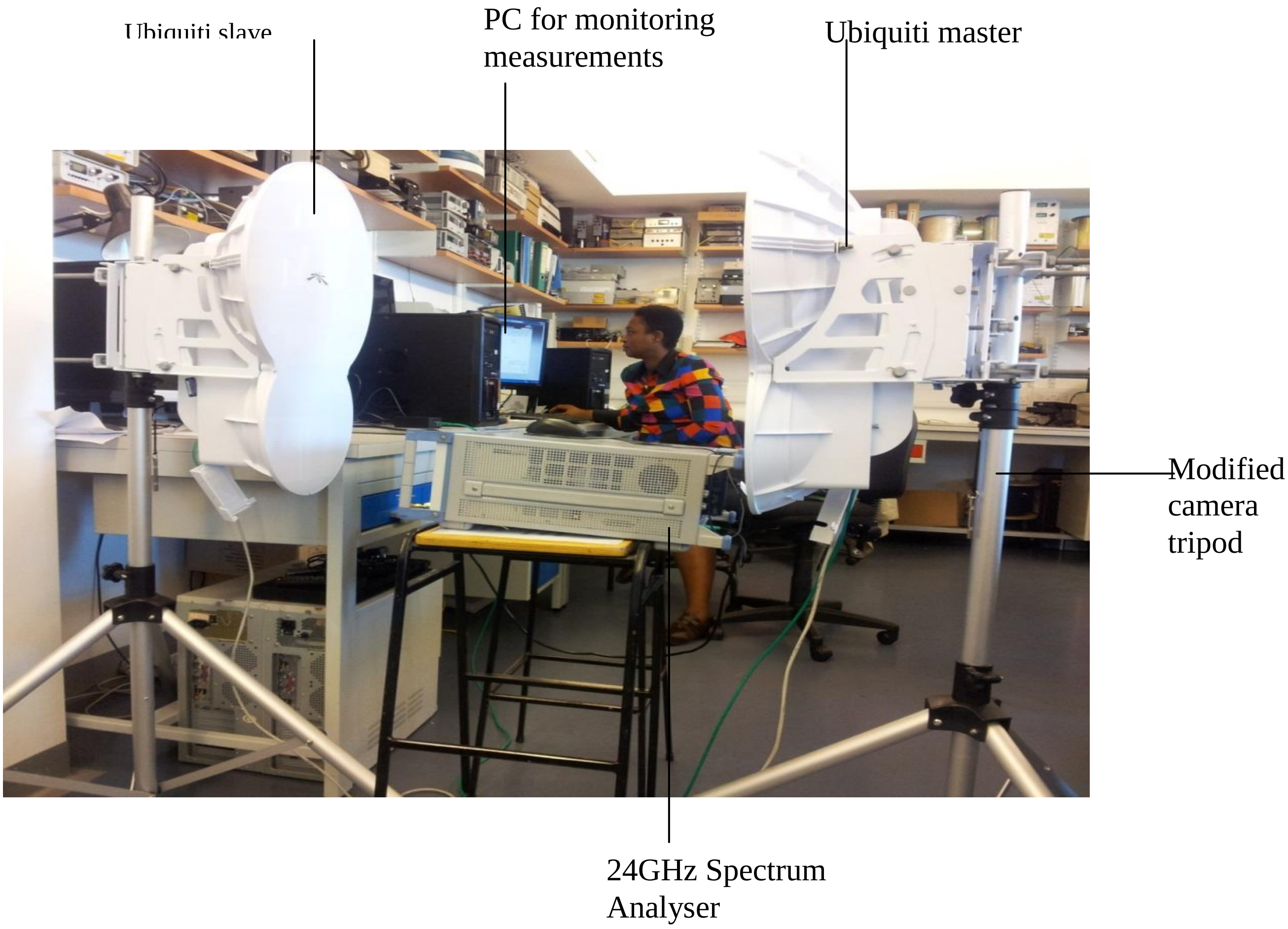
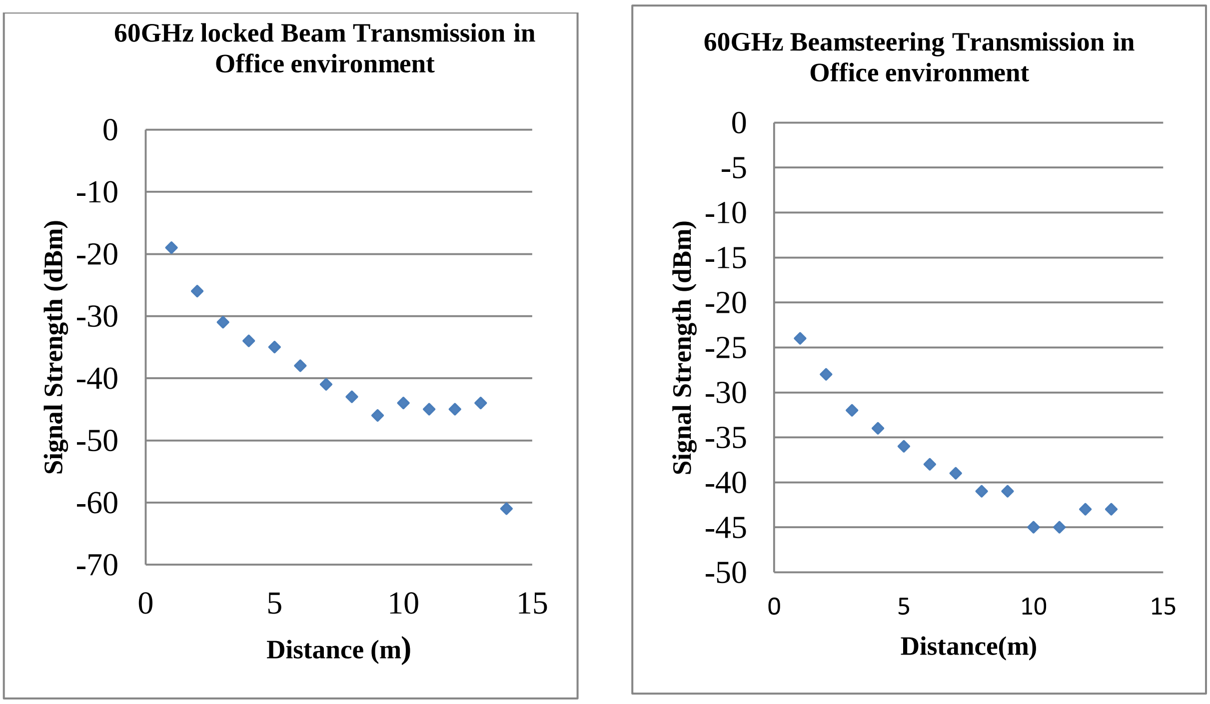


Figure.4: A set up of 24GHz point-point links for data transmission and throughput measurements

The setup for source and sink transceivers for the propagation measurements of 60GHz is shown in figure 3. The SiBeam P5 HDMI reference kits contain two host MCUs. One host is on the SK9200DB debug board and the other host is on the module board. The SBAM2 (SiBeam Applications Manager) software is installed on a PC with XP operating system to monitor status, set configuration and control other parameters of the WiHD transceiver modules. The SK9200DB Boards (Source and Sink) are connected to the PC through the USB cable, the source is connected to the Blu-Ray player via an HDMI cable, both source and sink are connected to monitors separately for monitoring signal transmitted and received. The beam locked array antenna has a narrow beamwidth, hence transmitted signal is targeted to the desired destination, while in the beam steering , though the mainlobe of the beam steered antenna is focused on the target, the reflections and multipath effects greatly induced the signal strength received..

Fig 4 shows the setup of the Ubiquity AF 24GHz ptp links transmitter and receiver. Both the transmitter and receiver are mounted on modified camera tripods. This affords repeated and accurate transmission measurements without the influence of human body. The transmitter and receiver are powered with 12volts, 1.4Amps .

V. RESULTS AND DISCUSSION



(a) (b)

Fig 5: 60GHz Transmission in a typical office (a) Locked Beam (b) Beam Steering

The beam locked array antenna has a narrow beamwidth, hence transmitted signal is targeted to the desired destination, while in the beam steering , though the mainlobe of the beam steered antenna is focused on the target, the reflections and multipath effects greatly induced the signal strength received. It is observed from figure 2.3 that the received signal strength in beam locked is higher compared to beamsteering in the experimental measurement carried out in a typical office setting (-19dBm and -24dBm) respectively. There is clear similarity between the two graphs, in that there is steady signal attenuation in received power with increase in distance up to 8m apart. This is in accordance with the Frii's law of propagation. In the beam locked scenario, there is a pick up at this point for 1m, followed by a constant transmission for another 2m away, after which a drastic drop of about -16dBm in the received signal with increase in the coverage. This could be accounted for by the obstruction of the glass door on the path of the transmission. The received signal in the beam steering case was relatively stable; this could have been due to multipath and reflections effects. It must be emphasized that indoor propagation at 60GHz was strictly on LOS, otherwise, any obstruction on its paths resulted in total links break.

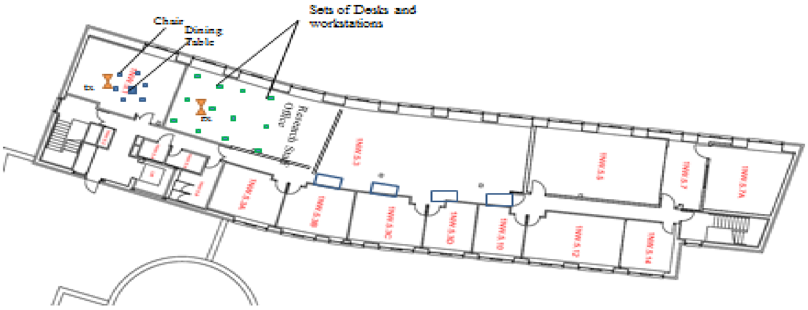


Figure.6: Floor plan of level five indicating signal attenuation measurement across offices

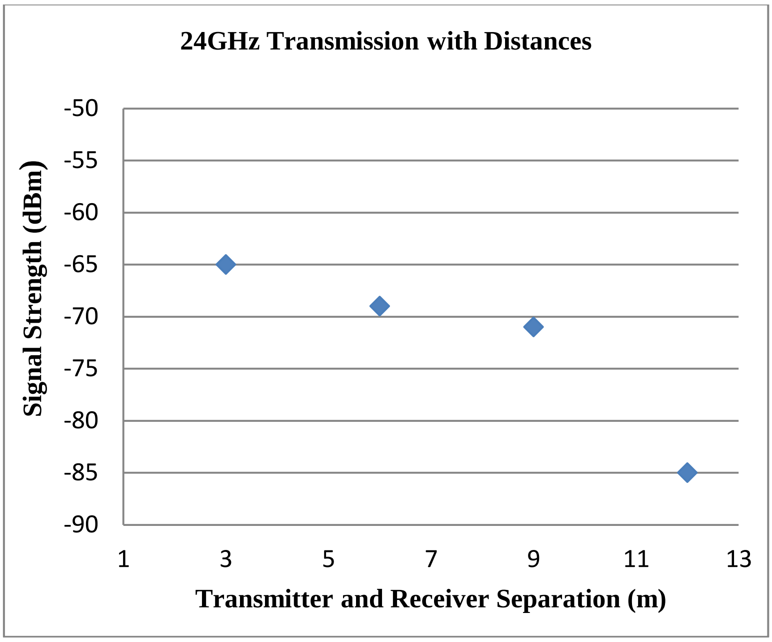
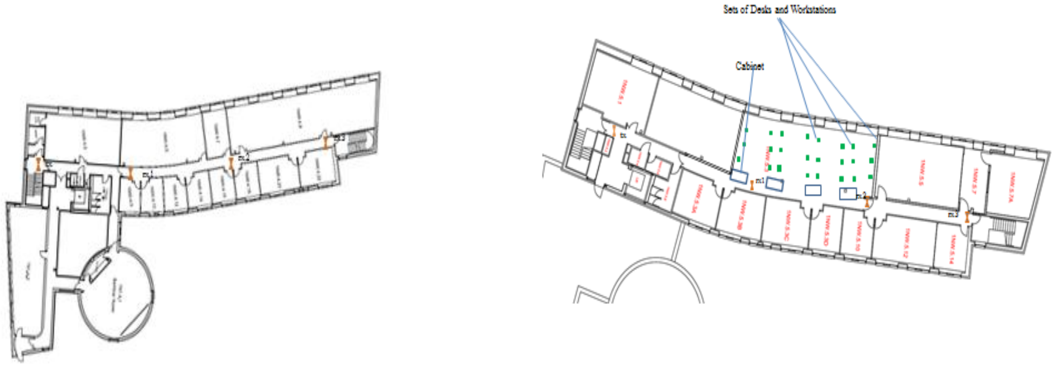


Figure.7: Indoor Propagation across offices against distance

Figure 6 is the building floor plan where the transmission measurements of 24GHz were carried out. There is a wall partition between the two offices where this experiment was conducted. Though there is signal attenuation with distance, the reception across the wall was acceptable especially at the lower modulation rate scheme with sensitivity of -88dBm for the air fiber ptp link. This confirms the capability of 24GHz compared to 60GHz to penetrate walls between offices in a modern building, hence WLAN deployed on this frequency band can be used for multimedia applications and gigabits required services in offices.



(a) (b)

Figure.8: Floor Plans of Network building indicating Signal strength measurement along the corridors (a) Level four (b) Level five

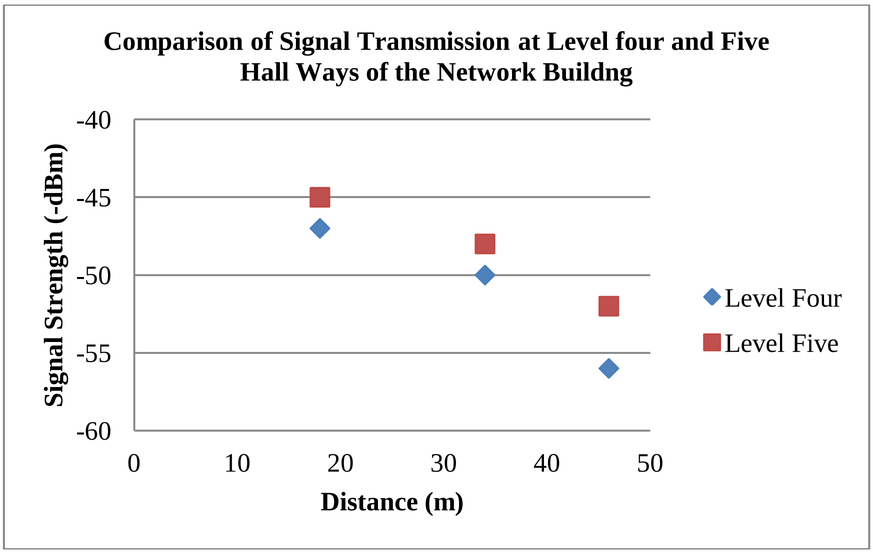


Figure.9: Signal Transmission against Distances at hall way corridors of level four and five of the network building

The floor plans of the locations where this experiment was conducted are shown in figure8. Relating the scenario in each floor with the results of transmission, shows that the presence of office equipment in floor five aided in good reception as a result of multipath and reflection propagation being experienced here. Unlike the case in floor four, though the long corridor served as wave guide to the transmission, the signal strength here is lower to what is obtained in floor five

5.1. COMPARISON OF 24 AND 60 GHZ INDOOR PROPAGATIONS:

Both frequency bands are millimeter waves with propagation characteristic of LOS. The experiment demonstrated this obviously in the 60GHz transmission. Any attempt to obstruct the path of transmission leads to total link break, whereas, in the case of 24GHz, there was still good receptions with couple of obstructions in the paths of transmission. This shows that 24GHz can be deployed with good performance in the NLOs situation for real time applications.

VI. CONCLUSION

The shortage of frequency spectrum as well as congestion in the microwave and lower frequency bands will not support the multimedia application requirements for the unprecedented growth in communication industry. Therefore, a solution is sought in the higher frequency spectrum for gigabits throughput realization. This paper has shown through empirical analysis, the possibility of engaging millimeter wave spectrum for the supply of the higher bandwidths that will meet the demands of gigabits per second data rates by multimedia applications. It has been demonstrated that a modern building office can be flooded with gigabit per second data rate especially when 24GHz device like the AF 24GHz ubiquiti point to point device is used in the indoor propagation scenario.

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