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Performance Evaluation of 24GHz Spectrum Indoor Wireless Radio Links

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***Abstract*— Wireless communication systems are susceptible to propagation impairments such as scattering, interference, multipath fading, and delay spread. Furthermore, unlike wired networks in which signals propagate in a confined media characterised by high quality system performance and high data rates up to 10Gbps, wireless signals propagate through the air and are as a result prone to security attacks.. As WLANs are becoming vital tools to meet the demand for wireless internet services, it becomes imperative to study novel approaches for achieving good access and high data rate transmission. The conventional WLAN network standards by IEEE802.11 family are characterised by maximum data rate of 54Mbps. This is below the required bandwidth for channel intensive applications such as multimedia services, uncompressed video streaming, fast file uploads and downloads. Also, the numerous subscribers competing for seamless wireless internet connection has overcrowded the network channels in microwave bands, resulting in poor performance and degradation of the entire WLAN networks. As much as 1Gbps and higher data rates communication are attractive for several application described above, this technological goal can only be realised by engaging millimetre wave (MMW) spectrum. The Spectrum bands at 24GHz, 28GHz, 38GHz and 60GHz are currently being focused on to support shorter-range, high-speed communication systems. These bands are capable of the Gb/s throughput as required by bandwidth intensive and multimedia consumer-oriented applications . The potentials of 24GHz spectrum for gigabits data rate delivery performance in real time applications was investigated in this work.**

***Keywords*— Beamforming; Gigabit; pathloss; Millimetre wave; and MIMO.**

I. INTRODUCTION

The allocation of ISM bands by FCC in 1985 for communication witnessed a huge explosion for the commercial development of WLAN and its products [1]. The real-time video streaming requires high data rate, delay constraints like in voice system, though the average bandwidth required by a single web user is around 10Kbps, the theoretical maximum data rate of 54Mbps in the IEEE802.11a is only sufficient for practical environment applications.

Data system requires 1-100Mbps and 10^{-8} BER with all bits received in error retransmitted, hence data transport capacity is an important metric parameter to determine the performance of ad-hoc networks in dense populated wireless system. The maximum data rate offered by the WLANs in the microwave bands is insufficient for the required channel demand by numerous media content, and the matching up with 10Gb/s in wired LANs [2].

This surge in service demand led to progressive generational development in wireless communication with data characterised by improved quality of service and significant cost reduction. One of such means is full duplex operations which permits simultaneous transmission and reception by a link pair. This affords optimal utilization of the channel medium to increase the overall throughput and system capability; the full access of both side of the links to the channel theoretically double the available bandwidth. This feature characterized the principle on which 24GHz band for wireless communication is based.

A. MMW Link budget Peculiarity

It is certain that the link budget at MMW is less than that of Microwave bands under equal conditions, while other loss (rain, foliage, scattering and diffraction) and fading factors increase the aggregate loss in mmw transmission, nevertheless, there is a large and untapped bandwidth of multi-gigabit potential in mmw, likewise, the short range in mmw gives room for densely packed communication link networks (frequency reuse) giving rise to compact, adaptive and portable integrated systems with increase security of links [3].

This feature can be exploited for indoor ultra-high speed short-range wireless communication, for multimedia applications and others, most importantly, the insurgence of a plethora of "channel intensive" multimedia applications has spurred the interest and increased efforts to engage mmw spectrum since the conventional WLAN systems are limited to maximum data rate of 54Mbps. Two paramount applications craving for higher data rates are ultra-fast file sharing and uncompressed high definition video streaming [4]

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B. Real Time Application Channel Characterisation Modelling:

The wave propagation in free space incurs a power reduction as a square of the separation between the transmitter and the receiver, when the distance is doubled, the power reduces by a factor of 4. This spread of radio waves as they propagate can be calculated by;

$$L = 20Log\frac{4\pi D}{\lambda} \quad (1)$$

However, the equation only holds for LoS or free space propagation and experience shows that LoS propagation holds only to the first 6m, beyond this, indoor propagation losses increase up to 30dB per 30m, indoor propagation losses can be significantly higher due to obstruction within the building [5] [6] .

A real-time channel model is therefore needed to determine the performance of a Wi-Fi network over a given range of coverage in indoor propagation. In this paper, the authors used actual measurements in ad-hoc network in sparsely populated environment for the channelization model using some commercially available hardware and software equipment from renowned manufactures. A large range of obstructions impair the strength of a transmitted Wi-Fi signal, therefore, channel models are environment dependent.

Some models like Log-distance Path Loss model and JTC Indoor Path Loss model are handy to evaluate the wireless network performance in indoor environment, but, a real-time application model would be most effective since the system will be deployed in such scenarios.

II. RELATED WORK

The research focus in the recent times has been on the realisation of gigabits/s require by the multimedia services; video conferencing, data streaming and many more services especially in an office environment as well campuses. Efforts have been concentrated lately on engaging the MMW for this purpose in the indoor wireless propagation. Many approaches have been used by various authors in this relevant area while it is very scarce with the authors to use real time measurement in their investigations and appraisals. Also, among the few MMW bands investigated, the newly opened bandwidth in 24GHz for wireless communication has not been adequately investigated for wireless indoor propagation in multipath rich environment. Hence, this work carried out an investigation on the performance evaluation of this band using physical devices for real time application services.

However, some of the findings of the previous authors related to this work are enumerate as follows:

The path loss and delay characteristics of indoor radio channels from 2.4 GHz to 24 GHz were carefully investigated in a typical modern building in [8]. The direct proportionality between the frequency and delay variation was established in their results. While [9] investigated the 28 and 38 GHz bands with encouraging results. Among the various channel modelling techniques used, ray tracing is prominent for radio propagation in the tunnels. This technique was engaged by [10] to analyse the propagation characteristics of lower frequency bands in rectangular roads and tunnels. The technique was adapted in this work for millimetre wave spectrum to analysis the channelization features of such in a curved corridor environment being a typical example of tunnel in a modern building. In a similar manner, the pathloss exponent for 24GHz in corridor propagation was derived by [11]using both experimental and empirical analyses, their results showed a lower value to the free space pathloss exponent and concluded that gigabit/s data rate transmission is achievable in such environment with this spectrum band.

C. MMW Bands Propagation at Rough Surface

The scattering of the impinging energy by a rough surface causes attenuation in the reflected parts of the transmitted signal. This being part of situation present in indoor scenario causes an obstruction due to level of protuberance of such materials on the path of the transmitted signal and this requires adequate attention. Rayleigh criterion helps to determine the roughness of the materials as presented in the equations below, which show the path and phase difference between the two rays [12]

$$\Delta l = 2h_c \cos\theta_i \quad (2)$$

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta l \quad (3)$$

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

Therefore,

$$h_c = \frac{3X10^8}{8f\cos\theta_i} \quad (4)$$

When hc < $\Delta\varphi$ gives a rough surface otherwise it is perfectly smooth surface and when hc is very small causes the two rays to be almost at the same phase.

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The curve below shows the comparison of the scattering property of millimetre waves on natural surfaces according to the above mathematical relationships.

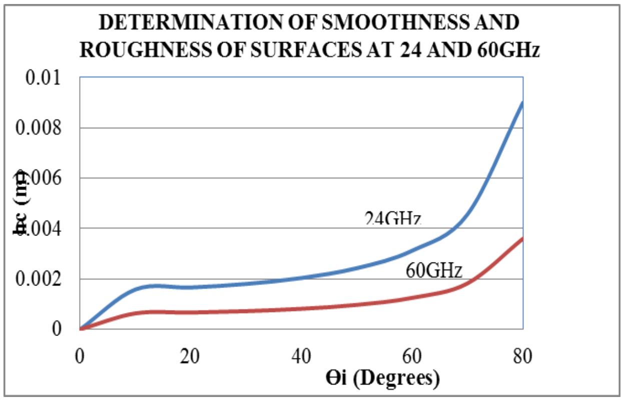

Fig 1: Comparison of hc plotted against the angle of incidence for 24GHz and 60GHz [13]

D. MIMO vs. Bandwidths and Transmitted Power

MIMO (Multiple in Multiple out) techniques improves communication reliability as well as increase data throughput through spatial division multiplexing (SDM), without necessarily increasing frequency band and power by using multiple antenna at the transmitter and receiver ends .The SVD-MIMO (singular value decomposition – multiple in multiple out) system can help in suppressing the signal interference as a result of lots of antenna by beam forming, this is effective in large scale MIMO systems[14, 15].

MIMO wireless is a major technological leap that permits Gb/s speeds in NLoS wireless networks as shown in the figure 2. The 10X10 MIMO system delivers 50b/s/Hz over 20MHz bandwidths. It is evident the high transmit power is not required to reach spectral efficiencies in excess of 10b/s/Hz. The improvement as a result of MIMO systems are due to array gain, diversity gain, spatial multiplexing gain, and interference reduction.

Likewise, the 24GHz point-point device used in this work takes the advantage of frequency diversity in MIMO arrangement incorporated in it to boost the delivery capacity, extend the range of propagation, and attain the gigabit/s data rate with bandwidth of 100MHz and transmitted power of 20dB.

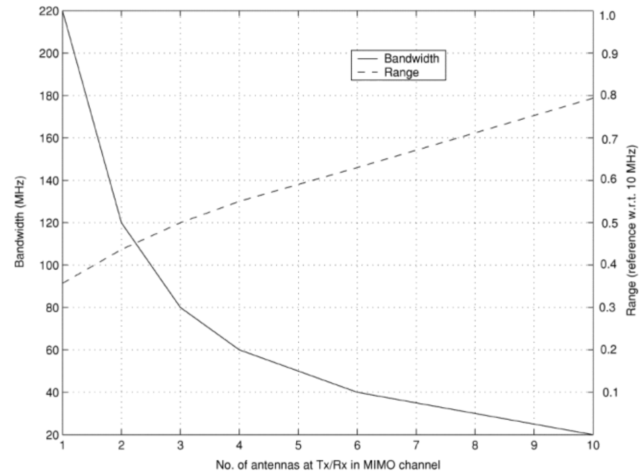

Fig 2: Bandwidth requirement and range of a 1-Gb/s link using MIMO technology [2].

III. EXPERIMENTAL METHODOLOGY

This work presents the experimental results regarding the performance of a WLAN network in NLoS scenario using an ad-hoc link deployed on the emerging 24.1-24.2 GHz unlicensed band shown in figure 6. The propagation loss in a tunnel with a cross dimension larger than the wavelength of the spectrum in free space was predicted by [16] using the ray optical model as shown in (5). This model was adapted in this work in matlab environment to investigate the potential of the 100MHz bandwidth in 24GHz band for high data rates and improved system capacity in such environment shown in figure 6. Comparison of the empirical results and simulation models was also carried out.

$$P_L = 10\log_{10}\left(\left(\frac{\lambda}{4\pi}\right)^2 \left|\frac{G_d}{r} + \sum_{i=1}^{\infty}\frac{G_i R_i}{r_i} e^{j\frac{2\pi(r_i - r)}{\lambda}}\right|^2\right) \quad (5)$$

Where

Pt and Pr are the transmitted and received power respectively, λ - signal wavelength, Ri is the product of reflection coefficients of the top and bottom walls, r and ri are the path lengths of the direct and i-th reflected ray respectively, Gd-Geometry mean of Tx and Rx antenna gains for direct wave.

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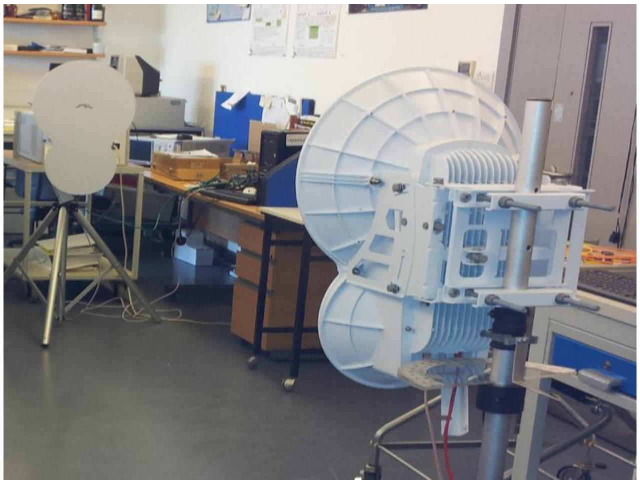

Fig 3: 24 GHz back-to-back set-up in full duplex operation

The experimental set up shown in Fig 3 consists of the 24GHz point-to-point link with maximum transmitter output power of 20dBm. It has delivery capacity of 1.4Gbps using the HDD in bidirectional mode at 6X64 QAM modulations scheme (highest) and is backward compatible to lower modulation scheme of QPSK through the automatic rate adaptation to accommodate low signal transmission. The feature enables a link pair to sustain up to 142.5 dB path loss when switched to basic QPSK modulation mode. Full duplex transmission is used with slight different carrier frequency of 24.1 and 24.2GHz; a bandwidth of 100MHz. The transmitting and the receiving terminals have an antenna gain of 33dBi each. For the experimental measurement, both antennas were mounted on tripods 1.7m above the floor level, and connected to PCs for signal transmission monitoring.Typical measuring screen shots at maximum and minimum modulation scheme transmission are shown in Figs 4 and 5.

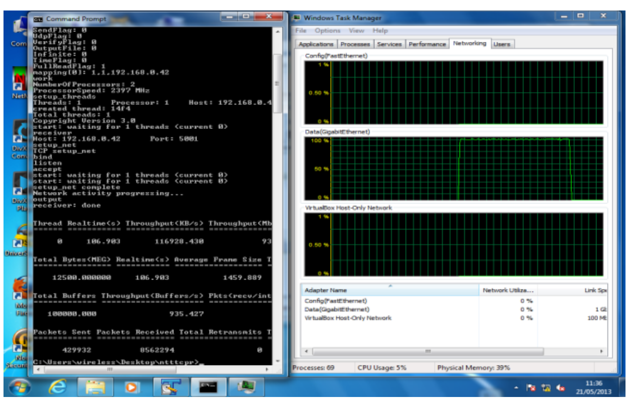

Fig 4: Network metering software displaying the throughput capacity of the PC used for the transmission

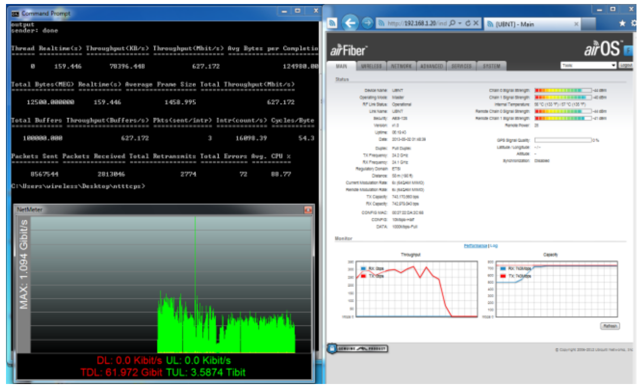

Fig 5: Transmission throughput at full duplex and 6X (64QAM MIMO) at both current and remote Modulation rate

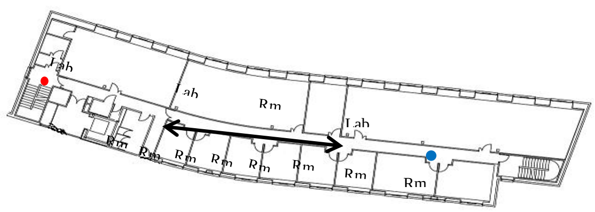

Fig 6: Floor Plan for Experimental setup Location [17]

IV. Measurement And Simulation Results

Firstly, the radiation pattern of the transceiver devices was evaluated using the setup shown in figure 3 and the recorded results were used for the graph as shown in figure7.

Also, the experimental setup was taking to the floor plan figure 6 where the measurements of signal transmission were carried out. Lastly, an algorithms was developed and simulated in matlab using the optical model depicted in (5) for the purpose of validation of the experiments ,there is a close agreement between the two sets of results as shown in figures 8-10.

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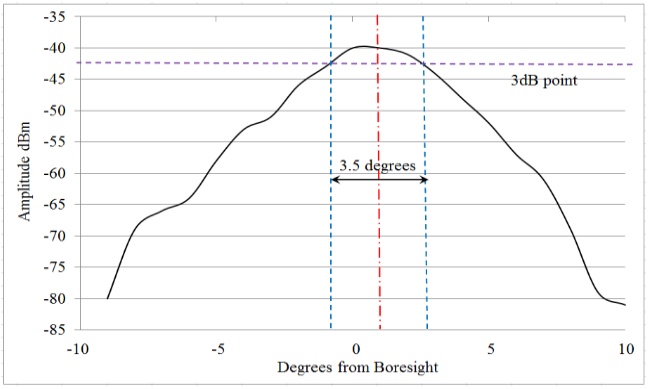

Fig.7: Radiation Pattern of airFibre Ubiquiti 24GHz Link

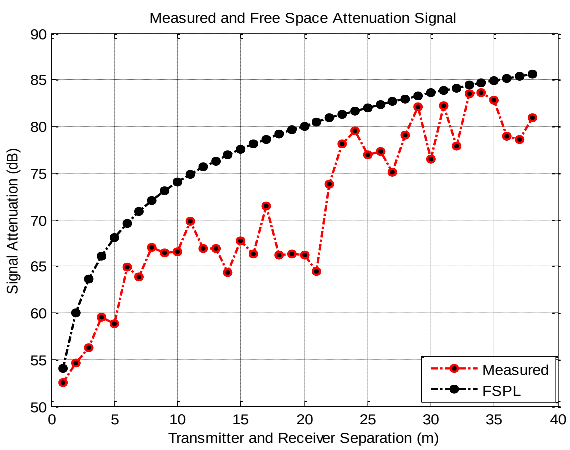

Fig.8: Comparison of Measured and Computed FSPL Values models

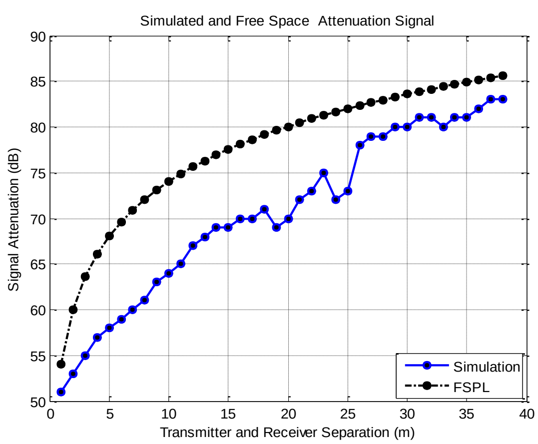

Fig 9: Comparison of simulation and Computer FSPL models

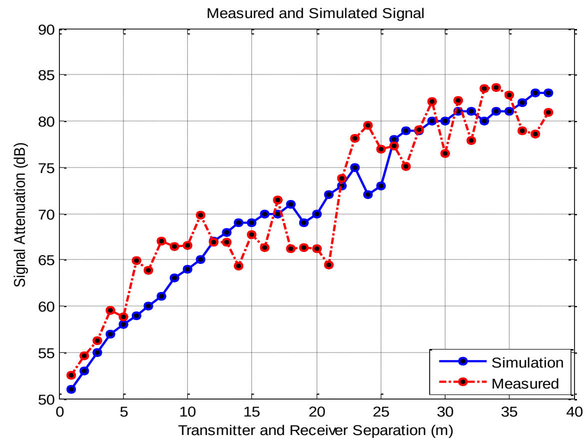

Fig.10: Comparison of simulation and Measured Values models

E. Discussion

Figs 4and 5 show the data transmission monitoring process across the links using net metering software. This was to determine the data transmission throughput in the real time applications and validate the theoretical specifications of the links.

The 3.5 degrees boresight of 24GHz transceiver as shown in the Fig 7 depicting the radiation pattern is significant. The divergence of the radiation pattern is confined within a narrow spread even in the clustered and potentially reflective scenario where this experiment was conducted. This aided the transmitted signal to focus and concentrated the transmitted power to the receiving terminal with little or no waste along the signal path, hence good signal strength was achieved at the reception end.

The comparison of measured values at the floor plan with the conventional FSPL was depicted in Figs 8-10. It is interesting to note a better attenuation rate at the considered environment compared with the FSPL situation. Again, the waveguide effects are established in this environment. The simulation model was in good agreement with the empirical models.

The directional antennas with narrow beam width (3.5 degrees) of the links mitigate the effect of fading due to multipath. This establishes the fact that a wireless network deployed on this band will perform well enough in an office environment to support multimedia application tasks.

V. CONCLUSION

The recorded experimental results demonstrated that a good data throughput is achievable up to a range of 40m in NLoS and multipath rich scenario in which the experimental measurement was conducted.

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This shows that the integration of directional antennas in mmw WLAN systems enhances the system performance by increasing the capacity and extending the range of reception. In effects interference was mitigated and multipath was equalized to achieve high data rate by the system pairs. It is can be concluded that wireless networks can now compare favourably with their wired counterparts for gigabit data rate delivery required by the numerous consumer applications while security is enhanced due to the antenna directivity, focusing the signal transmission with increased gain while suppressing interference towards the targeted users.

It has been demonstrated through this work, that high data rate transmission and good system performance using the 24 GHz frequency band are achievable and is an option for future in-building wireless networks. The results show that a hallway/corridor as well as offices in a modern building as well as typical office can be flooded with gigabit throughput wireless transmission to enable seamless communication and adequate bandwidth requirement for multimedia applications services.

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