Indoor Channel Measurement and Prediction for 802.11n System

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***Abstract*— Significant improvements in the quality and reliability of indoor WLAN communications are claimed for devices with MIMO technology applying 802.11n standards, that allow users to achieve a theoretical data rate up to 300-600 Mbps on a single transmission. This paper presents an analysis of a commercial 802.11n MIMO 2×3 dual band (2.4 and 5 GHz) system focusing on the operational throughput performance over an indoor environment for Line of Sight (LOS) and Non Line of Sight (NLOS) scenarios. Efforts on combined field strength distribution, throughput, propagation-channel environments, of this system will be elucidated. The work is focusing on the operational performance of the physical measurements and results compared with simulation model over an indoor environment.**

Keywords-component; MIMO, WLAN, IEEE 802.11n, Channel Bonding

I. INTRODUCTION

This work is preliminary to an investigation of the use of 802.11 WLAN devices in multi-hop scenarios [1]. It is envisaged that by employing a distribution coordination function [2-3], to evaluate the channel conditions that determine the data rates and taking into consideration the effect of interference on a basic service set [4] there is a potential to correct the fairness level using dynamic network allocation vectors and forcing handoffs.

Recent studies have evaluated the commercial performance of hot-spot connections using 802.11abg [5] and 802.11e using simulations to identify the quality of the connection through the Medium Access Control (MAC) [6].

In the same context the recent release of the 802.11n standard needs to pass through similar studies for its in-depth evaluation. Researchers in [7], investigated throughput using one transmitted stream to determine how it behaves in the ISM bands in an office environment. Using the same approach and considering the application of commercial wireless devices as was presented in [8], to perform TCP/UDP (Transmission Control/ User Datagram Protcol) throughput analysis, this investigation elucidates the UDP throughput performance versus distance in the indoor environment.

Simulation of the received signal distribution provides valuable information for wireless system applications, in which the propagation models are designed using either statistical or deterministic approaches. Statistical methods present several limitations, including low accuracy in small cell sizes and are not applicable to spatio-temporal channel characterization required for many contemporary wireless systems (OFDM, MIMO, UWB etc.) [9]. Therefore deterministic methods have become the preferred technique for channel propagation simulations. These models can be performed through the application of Maxwell's equation, e.g. using Finite Integration Technique (FIT) or Finite Difference, Time Domain (FDTD) or Shoot and Bounce Ray tracing techniques (SBR). 2D and 3D simulations are usually performed in accurate computational scenarios due to the high number of interactions (multipath) calculated [10].

A 3D FIT approach was applied in [9] to radio propagation calculations over an area of 400 m^2. The modelling geometry was based on a building layout with a specified location of windows, doors and significant metallic furniture through a simulation supported by a single processor computer with computing time less than 3 hours and 400MHz-900MHz frequency range. Results showed that error standard deviation was in the range 2- 3.7 dB which demonstrates a useful level of accuracy for modelling. A similar approach was reported [11] in which the simulation frequencies considered were below 1GHz for compact scenarios providing insufficient reliability at higher frequencies or for greater areas.

Such techniques clearly require a substantial computational effort which provides a substantial limitation in applications where wider areas and higher frequencies are required, making the FIT model unpractical [12], especially in terms of prediction accuracy and spatial detail.

Finite Difference Time Domain (FDTD) methods may be used to compute the electromagnetic response of a variety of arrangements and types of walls in a building. This is done by the discretizing the wall, corners and terminal locations into finite size building blocks and calculating the iterative field over the multiple scattering on the structures. FDTD provides simple programming and simple data base structure; however the excessive running time (55 hours) and memory requirement makes this technique limited. Ray tracing can be used to model the propagation but usually requires complex programming to determine the geometry of the traced rays [13].

II. THROUGHPUT MEASUREMENTS SETUP

The throughput measurement campaign was developed to measure the data rate achievable at different locations on the 3rd floor corridor from Chesham Building B Block at the University of Bradford campus. The measurements were computed by two stationary personal computers (PC), each one connected via ethernet to a commercial 802.11n wireless router having a 1x3 MIMO antenna array, evaluating the throughput obtained from MIMO2 to MIMO1 as shown in Fig. 1, which can operate at different frequencies and bandwidths.

The evaluation of each set of measurements, was performed in compliance with the 802.11n standard [14] over 10m to 50m,

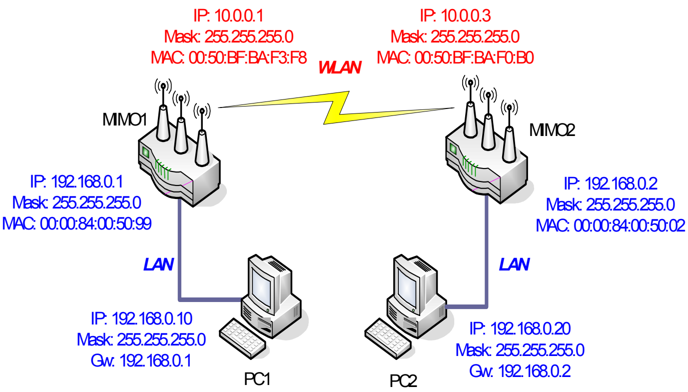

Figure 1. Throughput Measurements

A. Software Implementation

The throughput measurements were developed on UDP throughput mode due to the fast evaluation time for each position.

For this section, two different programs were applied to evaluate the throughput: IPERF [10] and IxChariot [11]. IPERF with its graphical interface (JPERF) provides a range of utilities to measure TCP and UDP characteristics and IxChariot is a sophisticated commercial package that enables performance assessment of network applications. Systems Structure

The PCs characteristics included 2 GB RAM memory and a 2.6 GHz single processor, using Windows XP professional operating system. Each PC was connected to a Dlink DAP2553 1x3 MIMO antenna via Ethernet using a Category 6 UTP cable, since it supports up to 10245 Mbps and the maximum throughput theoretically of a 2 stream MIMO systems is 300Mbps. The two antennas were linked together wirelessly in WDS mode. The software was deployed on both systems (PC1 and PC2).

B. Scenarios

Two different scenarios were established to evaluate the throughput performance on the MIMO antennas: the Line of Sight (LOS) Scenario, the Non Line of Sight (NLOS) Scenario. In each scenario, the antenna height was always 1m above the floor, for both the mobile (Rx) and the fixed unit (Tx).

The LOS scenario was implemented by installing the Tx antenna in a corridor in such a manner that all the measurement locations from the Rx antenna were able to achieve LOS reception. Five receiver locations were established for this scenario, separated by 10 m from each other in a linear distribution as shown in Fig. 2. The NLOS scenario was implemented by installing the Tx antenna in the corridor in a way that all measurement locations from the Rx antenna were able to achieve a NLOS reception. The same five receiver locations were established for the NLOS scenario as it was for the LOS scenario.

The aim of these scenarios is to evaluate the throughput over the distance in a LOS/NLOS setting for 2.4 and 5.2 GHz frequencies at 20 and 40 MHz bandwidth.

An additional throughput measurement was developed taking advantage of the LOS/NLOS scenarios and the configurable parameters from the antenna diversity analysis.

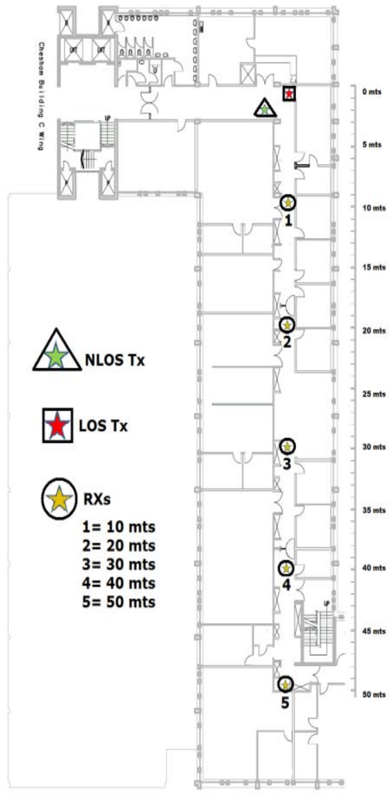

Figure 2. Line of sight Scenario

III. THROUGHPUT MEASUREMENT RESULTS

Each value represented in the following graphs was averaged over 5 measurements per location.

Fig. 3 describes the average (mean) and the maximum (peak) values obtained from the throughput measurements obtained from the LOS scenario at each of the 5 locations. A particular observation on the achievable throughput using 40MHz bandwidth is that at some points it doubles the 20 MHz throughput. In the majority of cases using 40 MHz, 5.2 GHz achieves higher date rates compared with the 2.4 GHz frequency configurations.

Fig. 4 shows the mean and the peak values obtained from the throughput measurements obtained from the NLOS scenario with the system operating at 2.4 and 5.2 GHz frequencies, using 20 and 40 MHz transmission bandwidth at each of the 5 locations. In this scenario there is a noticeable decrease of throughput as the distance between the Tx and the Rx increases. Still at around 50 meters distance (location 5) the throughput is 90-100 Mbps (5GHz-40MHz), which is considered a very good performance for a NLOS scenario.

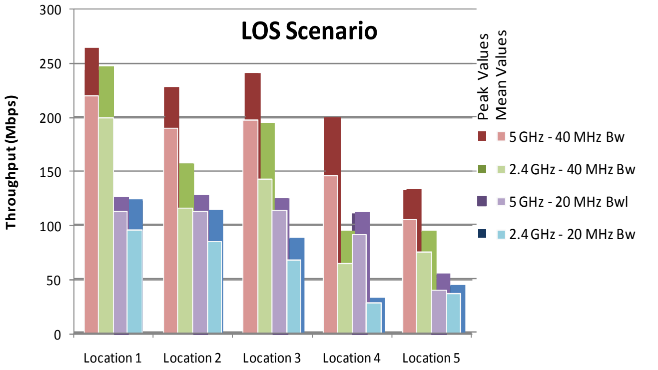

Figure 3. Averaged Throughput over Locations for LOS Scenario

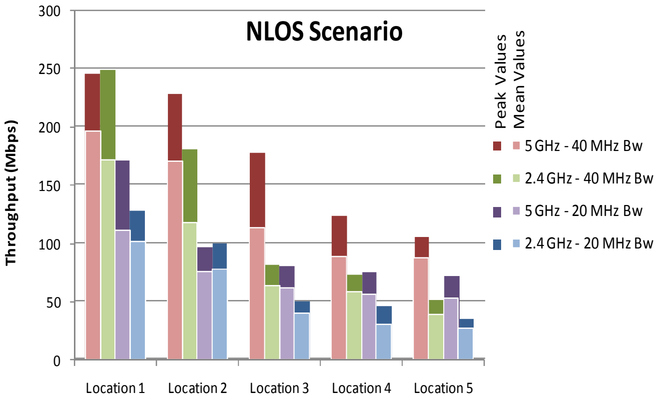

Figure 4. Averaged Throughput over Locations for NLOS Scenario

IV. SIMULATION MODEL

The simulation was performed through the 3D Shoot and Bounce Ray (3D SBR) technique, using 0.2˚ ray spacing, 7 reflections, 2 transmissions and 0 diffractions, which allowed evaluation of the paths launched from the transmitter. Following the basic multipath mechanisms (reflection, diffraction, transmission and scattering), it was possible to determine the rays reached by the receiver and therefore to calculate the path loss. Applying the image method approach the ray tracing technique captures precisely the large structure. The 2D and 3D simulations are performed in computational scenarios for accuracy due to the high number of multipaths calculated [10]. The Wireless InSite model included the configuration of specific parameters for its complete simulation: waveform, antenna, transmitter, receiver, model, materials and output.

The construction of the model was corroborated by the corridor layout used for the physical measurement. The model therefore has the same dimensions as the building corridor corresponding to 64 x 26 x 3 meters. The model was successfully completed by detailed modeling as shown in Fig. 5, establishing two types of walls: 20 cm thick and 12 cm thick (block material) according to the floor layout seen in table 1.

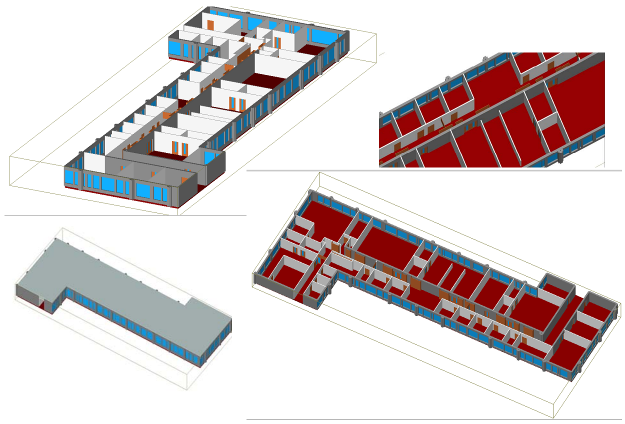

Figure 5. 3D Indoor Environment Model.

TABLE I
WALL TYPES FOR INDOOR DATABASE

Type	Layer Thickness
Wall	12cm - Block
Wall	20cm - Block
Door	6cm - Wood
Window	1cm - Glass

Two types of doors were identified, wood doors and crystal doors, the latter having two sub classifications: 2 glass crystal door and the 4 glass crystal door. The floor and the ceiling, 3m above the floor, were defined as block material. A second ceiling was simulated, 2.5m above the floor, acting as the foam ceiling tiles with 3cm thick of a soft dielectric material.

V. RSSI MEASURMENT AND SIMULATION RESULTS

The first measurement campaign was developed to evaluate the field distribution strength using a laptop and the MIMO 2×3 system along the corridor of Chesham Building section B, 3rd Floor, at the University of Bradford.

The physical model was performed in a layout with the total corridor space divided into 1m^2 sections obtaining a total of 90 locations. Each section was evaluated for 5 Received Signal Strength Indicator (RSSI) values over two frequencies (2.4 and 5 GHz) using the 802.11n standard at 20 MHz bandwidth.

The 3D RSSI Scenario comprised of 90 receiver locations was divided into the Rx Route (69 locations), and the Rx Grid (21 locations) for practical analysis. The Rx Route is a route of receiver locations along the entire corridor; every single one with the same characteristics. The Rx Route has a part of LOS and NLOS receivers. The Rx Grid is a 7x3 Grid of receiver locations set in LOS as shown in Fig. 6.

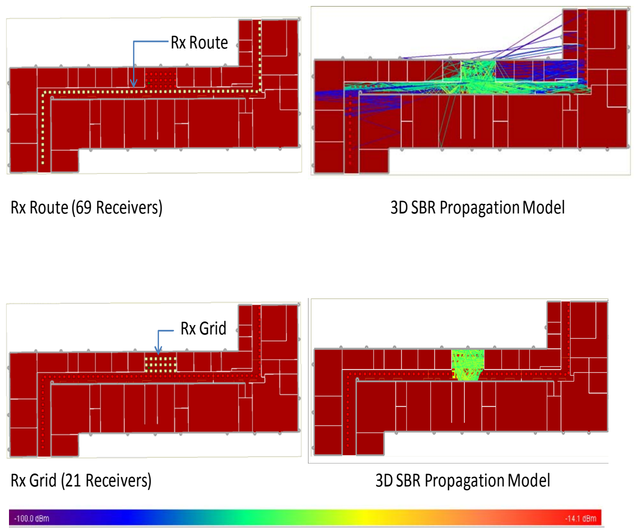

Figure 6. 3D RSSI Scenario Simulated Results.

Fig. 7 shows the field strength distribution obtained from RSSI measurements campaign along the corridor. The graph shows 13 scales from -9 to -100 dBm values, each scale using a 6.9 dBm range. The distribution was implemented for 2.4 and 5 GHz measurements. Both distributions show that in 5.2 GHz configuration, the signal strength is distributed over a less coverage area compared with 2.4 GHz, but achieving a higher intensity over closer areas.

Figure 7. RSSI Measurement Results for 2.4GHz and 5GHz.

Two simulations were averaged to analyze the propagation behaviour, the graphs in Fig. 8 show the comparison of the received signal strength measured per receiver location and the simulation of the 3D RSSI Scenario results. The simulated results are an average of the received signal of the maximum and minimum transmission power of the antennas. These are at 2.4 was from 17 to 11 dBm, and 5 GHz from 18 to 9 dBm, confirming the similarity of the values simulated.

Measured and simulated results were analyzed statistically concluding in a correlation between their signals of 86% at 2.4 GHz and 96% at 5 GHz. The total correlation of the physical and simulated model was of 92%. This indicates that the approximation from the simulation to the real world measurements were statistically similar.

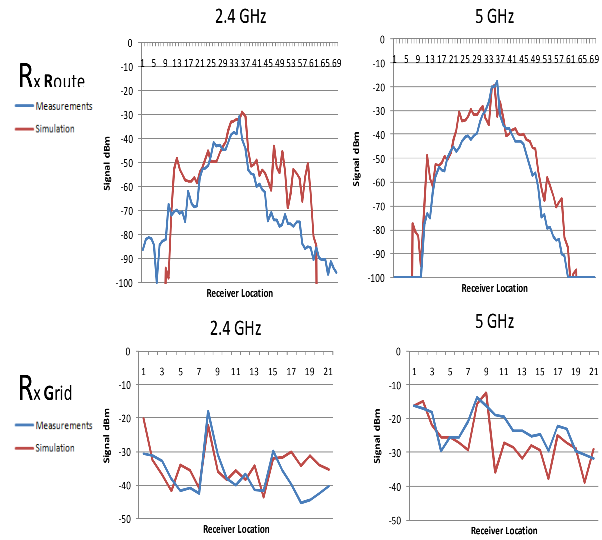

Figure 8. Measurements and Simulation Results Comparison

VI. CONCLUSIONS

The analysis of throughput values obtained from Line of Sight and Non-Line of Sight scenarios provide an experimental insight into the performance of MIMO systems deployed using the 802.11n standard in a typical multi-storey office building, reaching 250 and 296 Mbps for NLOS and LOS respectively (for 10 m distance). The achievable bit rate for a MIMO system is much more reliable when compared to a SISO connection. Furthermore the 802.11n channel bonding option provides remarkable throughput increase, compared with 802.11a/b/g.

The Implementation of a simulated propagation model using 3D SBR provides a good estimation of the channel propagation without demanding an extraordinary computational effort. Th investigation found a high correlation for 2.4 GHz and 5.2 GHz frequencies (86% and 96% respectively) between measured and simulated data . By modelling a MIMO system in an indoor environment, it was possible to determine the signal strength distribution and its achievable throughput for different locations. Despite the accuracy of the results obtained in this investigation, the modelling process remains rather complex, which might limit its applicability in future work.

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