MIMO Indoor Propagation Prediction using 3D Shoot-and-Bounce Ray (SBR) Tracing Technique for 2.4 GHz and 5 GHz

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Abstract— **The performance of voice, video and data streaming applications using the recently developed standard 802.11n with its MIMO antenna options, strongly depends on the nature of the environment. Although many authors have provided evidence on the effectiveness of this technology in field strength distribution, throughput or propagation-simulation environments, work linking all of these parameters is limited. This paper provides a comparison of metrics for a 2×3 dual-band MIMO system operating at 2.4 and 5 GHz in a typical office building, obtained using a commercial wireless router. The measurements are consistent with simulation results obtained using a 3D Shoot and Bounce Ray (SBR) software. Predictions of the radio propagation over an area of around 1600 m^2 required an evaluation time of less than 1 hour in a single processor computer for both frequencies. Agreement between predicted and measured Received Signal Strength Indicator (RSSI) values are acceptable, with the conclusion that such simulation methods provide an accurate, affordable and time efficient alternative to measurements for the investigation, modelling and planning of WLAN networks using MIMO technologies.**

Keywords: MIMO, WLAN, IEEE 802.11n, Channel Bonding.

I. INTRODUCTION

The indoor wireless propagation channel between two antennas is influenced by numerous interactions between the transmitted signal and objects in the physical environment, creating multiple wavefronts. These interact to determine the pattern of path loss, shadowing and localised fast fading of the field.

Simulation of the received signal distribution provides valuable information for wireless system applications.

Propagation models are designed using statistical and deterministic approaches. Statistical methods present several limitations, including low accuracy in small cell sizes and inapplicability to spatio-temporal channel characterization and hence to a majority of emerging wireless systems (OFDM, MIMO, UWB etc.) [1]. Therefore deterministic methods have become the preferred technique for channel propagation simulations. Deterministic models can be performed through the application of Maxwell's equation (i.e. FIT, FDTD) or by Ray tracing techniques (SBR). In view of the high number of multipath interactions involved in the calculations, either 2D or 3D simulations may be performed to provide sufficient computational accuracy for any given scenario [2].

A 3D Finite Integration Technique (FIT) approach was applied in [1] to radio propagation calculations over an area of 400 m^2. The modelling geometry was based on a building layout replicating the specified location of windows, doors and significant metallic furniture in a simulation supported by a single processor computer with computing time less than 3 hours across the 400MHz-900MHz frequency range. Results show error standard deviation was in the range 2 - 3.7 dB which proved sufficient accuracy in the model. A similar approach was reported in [3] where simulation frequencies below 1GHz were considered for small scenarios giving insufficient reliability for higher frequencies or greater areas.

The high computing effort applied in this technique is noticeable due to the long period taken to both establish and run the simulation. This provides a substantial limitation on investigations where wider areas and higher frequencies are required, making the FIT model impractical [4], especially in terms of prediction accuracy and the spatial detailing.

Finite Difference Time Domain (FDTD) methods compute the electromagnetic response of a mixture of walls in a building. This is done by the discretizing the walls, corners and terminal locations into finite size building blocks and calculating the iterative field over the multiple scattering from the structures. FDTD provides for simple programming and a simple data base structure; however the excessive run time (55 hours) and memory requirement limits the applicability of this technique.

Ray tracing requires rather complex programming, but may be applied to large scale and complex geometries [5].

Although the software code is usually complex to design and develop, a more user friendly software application can be applied to a ray based technique. This would not only overcome the commonly known disadvantage but also provide more promising solutions for the calculation of higher frequencies or wider areas.

Ray tracing combines the Shoot and Bouncing Rays (SBR) technique and the Uniform Theory of Diffraction (UTD)[6] which makes 3D SBR an efficient propagation prediction tool for simulation comparison with indoor measurements [7-9], including frequencies up to 5GHz [7].

The flexibility of the ray tracing method provides a broader scope for different network analysis tools, even for the prediction of field strength in cellular mobile networks [10], taking advantage of the detailed scenario that could be evaluated using the topology and the lossy material structure specifications that produce a realistic model and therefore a scalable accuracy in the results.

The implementation of SBR allows the comparison of commercial equipment using standardised regulations and frequencies to obtain the performance for wireless systems usually developed for Wireless Local Area Networks (WLAN), which with the use of 3D ray tracing allows evaluating several standards over real world scenarios such as 802.11b/g in [11-12], 802.11a in[13] and even the simulation of the most recent 802.11n [14].

The study presented herein is based on a 3D SBR technique for the accurate prediction of field strength distribution over an area of 1728m^2 with frequencies of 2.4GHz and 5GHz.

II. MODEL

The simulation was performed through 3D Shoot and Bouncing 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 reaching the receiver and therefore to calculate the path loss. Once the ray-launching computations have identified the approximate ray-paths, use of the image technique permits a more precise determination of the ray geometries having reduced the number of structures involved in ray interactions. Depending on the scenario and required accuracy, either 2D or 3D simulations may be performed [2]. The Wireless InSite model allowed for the configuration of specific parameters for its complete simulation: waveform, antenna, transmitter, receiver, model, materials and output.

The waveform type used for the simulations was a Gaussian waveform of 5230 MHz and 2410 MHz frequencies with 23 MHz bandwidth.

The antenna type implemented were Linear Dipoles, vertically polarized with a 6 cm length, and maximum receiver sensitivity of -100 dBm, using the Gaussian waveform previously defined. Two transmitter and three receiver dipole antennas were used with a quarter wavelength ($\lambda/4$) separation.

The construction of the model followed the corridor layout used for the physical measurement. The model therefore has the same dimensions of the building corridor corresponding to 64 x 26 x 3 meters as shown in Fig. 1.

The model was successfully completed by detailed modelling establishing two types of walls: 20 cm thick and 12 cm thick (block material) according to the floor layout seen in Fig. 1 and Table 1.

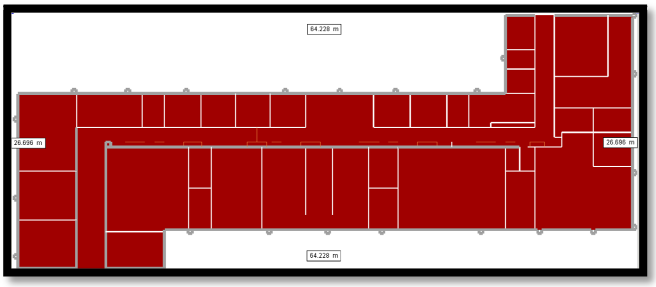

Fig. 1. Floor Plan Simulated Model Dimensions.

Two types of doors were identified, wooden doors (office doors) and crystal doors, the latter having two sub classifications: 2 glass crystal door (meeting rooms) and the 4 glass crystal door (labs doors), shown in the Fig. 2. Furniture such as wooden closets and door frames were also included in the model.

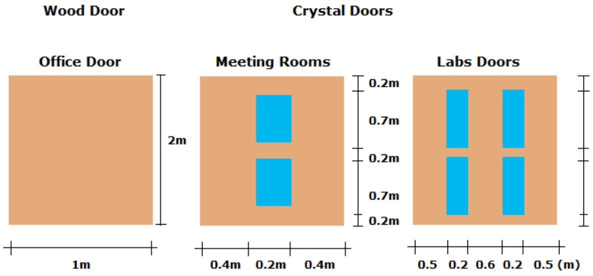

Fig. 2. Doors Dimensions.

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. Exterior windows and frames were also confirmed on a physical comparison survey.

The properties of the materials used in the model were defined according to the investigation described in [5], which defines the electrical parameters for building materials.

TABLE I
WALL TYPES FOR INDOOR DATABASE

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

The outputs required for the overall environment was the received power over each receiver location (90 in total) as well as the power delay profile for the NLOS and LOS simulated scenarios.

III. MEASUREMENTS

The first measurement campaign was developed to evaluate the field strength distribution using one laptop and two MIMO 2x3 systems 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 shown in Fig. 3 obtaining a total of 90 locations. Each section was evaluated for 5 RSSI values over two frequencies (2.4 and 5GHz) using the 802.11n standard at 20 MHz bandwidth.

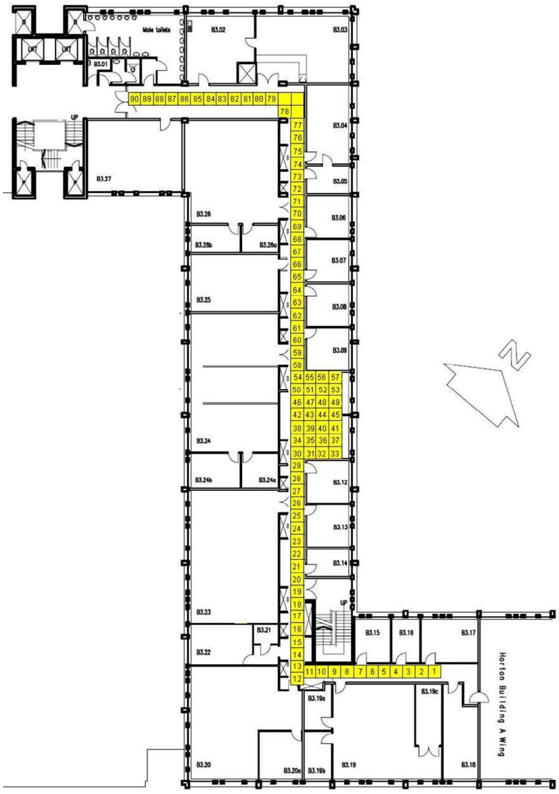

Fig. 3 RSSI Scenario.

The receiver (Rx) and transmitter (Tx) antennas were located 1m above the floor. The receiver antenna was the one moving along the corridor, always facing in the direction of the transmitter antenna. The transmitter antenna was at a fixed position on point 55 shown in Fig. 3, facing point 50 for all the measurements in this campaign. The Rx antenna was positioned successively at all points (locations 1-90), capturing five values per location of the Received Signal Strength Indicator (RSSI) from the link established with the Tx.

The transmitter and receiver systems were Dlink DAP-2553 access points operating at dual band frequencies of 2.4 GHz (2400 ~ 2483.5MHz) and 5 GHz (5.15 ~ 5.35GHz and 5.47 ~ 5.725GHz for Europe), with MIMO 2x3 antennas arrangement. The antennas have additionally the feature of a Power over Ethernet Port. This equipment performed according to the 802.11n standard and are compatible with 802.11a/b/g.

Two software packages were used to measure the received signal strength, Inssider [15] and Wavemon [16]. The PC characteristics included a 3 GB RAM, AMD Athlon dual processor at 2.10 GHz, in a Windows Vista operating system.

IV. RESULTS

The 3D RSSI Scenario comprised of 90 receiver locations was divided into the Rx Route (69 receivers), and Rx Grid (21 receivers) for practical analysis. The Rx Route is a route of receiver locations along the complete corridor, having partly Line of Sight (LOS) and partly Non Line of Sight (NLOS) locations. The Rx Grid locations are all LOS.

Fig. 4 shows the simulated field strength distribution with antennas operating at 5 GHz and 2.4 GHz, setting the maximum transmission power, at 18 and 17 dBm respectively. This distribution shows a good agreement with the field distribution measured in the RSSI measurement campaign. The evaluation time for this simulation was 53 minutes for 2.4 GHz and 58 minutes for 5GHz.

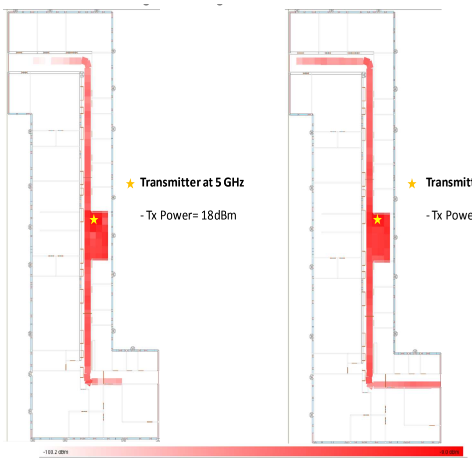

Fig.4 Field Distribution Simulated for 2.4 and 5GHz

The average received power over five measurement results for each location and at each frequency are shown in Fig. 5, compared to the results of the simulation, obtained on the assumption that the transmitted power was mid-way in dB between the minimum and maximum available transmit power levels (11 to 17 dBm at 2.4 GHz and 9 to 18 dBm at 5 GHz). The results show generally good agreement between simulation and measurement, although the simulation underpredicts at 5 GHz in the region between locations 43-51 for the Rx Grid measurements.

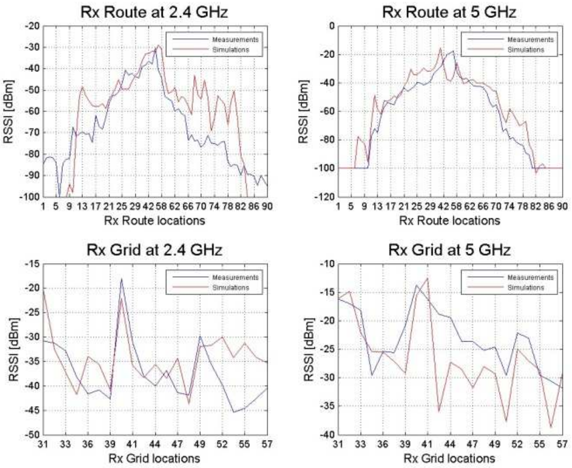

Fig. 5. Measurements and Simulation Results Comparison.

Measured and simulated results were analysed statistically, concluding that the correlation between simulated and measured signals in dB was 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.

V. CONCLUSIONS

The Implementation of a simulated propagation model using 3D SBR provides a good estimation of the channel propagation without demanding an extraordinary computational effort. The developed investigation resulted in a high correlation for 2.4 GHz and 5.2 GHz frequencies (86% and 96% respectively) between the data measured and the one simulated. By reproducing a MIMO system in an indoor environment, it was possible to determine the signal strength distribution and its achievable throughput over different locations. Despite the accuracy of the results obtained as part of this investigation, the model does have its limitations in terms of the considerable effort required to establish the building layout and materials properties, which could limit its reproducibility in future investigations.

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