Indoor Wireless Channel Modeling from 2.4 to 24GHz Using a Combined E/H-Plane 2D Ray Tracing Method

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Abstract: Future wireless systems are moving to high frequencies for additional bandwidth and frequency reuse. This makes it very important to have accurate and time-efficient models for system planning. In the past, we have published measurement results for an indoor-channel investigation from 2.4 GHz to 24 GHz. In this paper, we propose a new combined E/H-plane 2D ray tracing method. This method includes 2D ray-tracing calculations from both horizontal and vertical sections (E/H planes). The method predicts loss accurately for both line-of-sight (LOS) and non-line-of-sight (NLOS) paths at five frequency bands from 2.4 GHz to 24GHz. In addition, it predicts delay spread for line-of-sight paths well, but fails for non-line-of-sight paths.

I. INTRODUCTION

Current wireless network standards support data rates from 2Mbps to over 50Mbps. The IEEE 802.11 (a, b and g) systems have been widely used. They are currently operating at 2.4 GHz and 5 GHz. In addition, future wireless systems have been proposed at 17 GHz (HIPERLAN II) and 60 GHz for the large bandwidth and high data rate. We have previously published measurement results of an indoor-channel investigation for five selected frequency bands from 2.4 to 24 GHz [1]. In addition to 2.4, 5 and 17 GHz, the 10 GHz (amateur radio) and 24 GHz (Industrial, Scientific and Medical) bands have been added for comparison. The indoor measurements were done in the Moore Lab at Caltech. For the purpose of system planning, a prediction tool would be valuable to avoid time-consuming measurements. 3D ray tracing methods [2-3] can handle these problems but need detailed 3D information and long processing time. In this paper, a new combined E/H-plane 2D ray-tracing method is proposed. It gives quite good results in predicting the measurement data and reducing processing time.

II. COMBINED E/H-PLANE 2D RAY TRACING METHOD

We did indoor channel measurements in the hallway of the 3rd floor of the Moore building. Since the width of the hallway is not too large, there exist strong reflection paths from the walls on both sides. Also, many air ducts and light strips on the ceiling contribute strong additional multipaths to the channel. It is almost impossible to get a reasonable prediction of the channel by any 2D ray-tracing method. However, a general 3D ray-tracing requires more time for both geometry input and numerical computation. Therefore, a combined E/H-plane 2D ray tracing method has been developed to save time and retain accuracy.

In the LOS scenario of this method, two planes (vertical and horizontal) are cut through both the transmitter (Tx) and the receiver (Rx), (Fig. 1). The 2D ray tracing code is applied to both these planes and the results are summed up for a complete set of signal paths. By considering these two principle planes, most strong multipaths are included except the 2nd and high order paths that cross the planes. The processing time is now proportional to ($2N^2$) instead of (N^3) as required for a general 3D ray-tracing method. Even though some accelerating algorithms have been developed recently for 3D ray-tracing [4], this combined 2D method is still a very promising way to handle the complex indoor environment with reasonable time and accuracy. Another advantage of this method is that the ray calculations can be naturally divided for parallel processing. This further reduces the simulation time, which is extremely helpful for a large problem.

For the NLOS scenario, there is no way to cut the vertical plane to include both transmitter and receiver. We have defined new transmitter sources to handle this problem (Fig. 2). All additional sources are generated by diffraction from the original Tx, or its image reflected by the ceiling or floor. All have a LOS

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path to the Rx. After finding the values of these sources from diffraction formulas, we can apply the normal 2D ray-tracing method as before and sum them with the horizontal ray-tracing results. This procedure is quite similar to the LOS case. The only difference here is that each new source requires the consideration of an additional vertical plane. This calculation is also included as an option in the numerical ray-tracing code. The NLOS case has a computation time proportional to mN^2, where m is an integer ($m > 2$), depending on how many diffraction sources are taken into account. Environment geometry determines the number of diffraction sources necessary.

The formula for the link performance calculation is given in (1-1), where R_i is the product of the reflection, transmission and diffraction coefficients associated with the i^{th} path, L_i is the total length of the i^{th} path, and G^{Tx} and G^{Rx} are antenna pattern functions for the transmitter and receiver. Pattern measurements were made in an anechoic chamber. The Hann window and IFFT are applied to find the time domain profile to calculate the RMS delay spread.

$$S_{21}(f)=\sum_{E/H\_Plane}\sum_{i=1}^{M_{E/H\_Plane}} R_i\cdot\left(\frac{\lambda}{4\pi L_i}\right)\cdot e^{-j\cdot kL_i}\cdot G_{E/H}^{Tx}\left(\theta_{E/H\_Plane}\right)\cdot G_{E/H}^{Rx}\left(\theta_{E/H\_Plane}\right) \qquad (1\text{-}1)$$

A graphical user interface program has been developed using MATLAB. It takes the positions of the transmitter and receiver and the 2D E/H cutting plane geometry files as input parameters for ray-tracing calculations. Different code is used for the LOS and NLOS scenarios as described before.

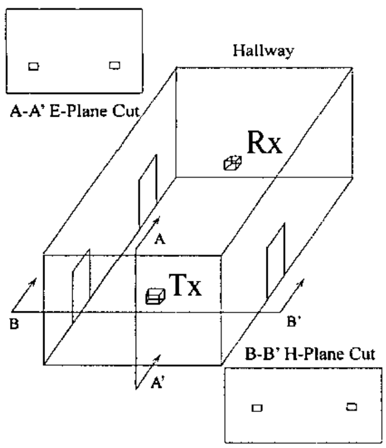

Fig. 1 Combined 2D ray tracing for LOS.

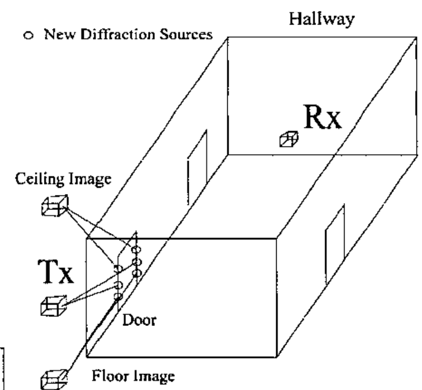

Fig. 2 Modified 2D ray tracing for NLOS.

III. EXPERIMENTAL SETUP

We have made two indoor channel measurements: path loss and RMS delay spread. For the path loss measurement, an Anritsu 68397 signal generator provided the signal for the transmitter and an HP 8563 spectrum analyzer measured the signal at the receiver. An HP8722 vector network analyzer was used for delay spread measurements. HP8349B and Litton TWT amplifiers were used to improve the signal-to-noise ratio. A pair of AEL broadband horn antennas that cover all bands of interest with a gain of 8-10 dB were used. We wrote LABVIEW programs to extract measurement data from those instruments and also control the movement of the receiver cart using the GPIB. This gave us the ability to take data for a signal plot over a long distance.

Measurements were made to extract electrical parameters for indoor construction materials. A good material model is very important for accurate ray-tracing. In the past, people have published results on the electrical properties of materials at microwave frequencies [5], [6]. For this work, we made free-space TRL measurements to find the microwave properties of three construction materials (plasterboard, glass and wood) at five selected frequency bands. The measurement data is shown in Fig. 3. They are comparable to the results that have been published before.

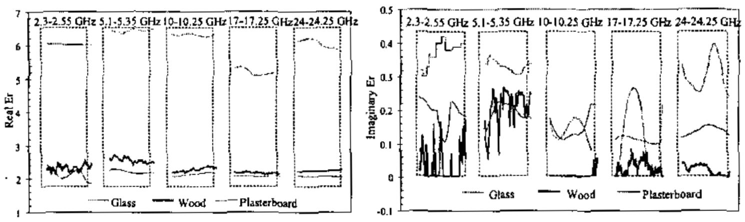

Fig. 3 Comparison of three different materials: glass, wood and plasterboard.

IV. SIMULATION VS MEASUREMENT

Simulations were performed and measurements made for the 3rd floor of Moore building (Fig. 4). In the LOS scenario, the transmitter is located in the center of the hallway, and in the NLOS scenario, the transmitter is located in one of the side rooms. The receiver is moved along the hallway controlled by the computer on the cart, while path loss and power delay profile data were measured. The cart is moving quite slowly to avoid frequency shifts. The cart can also be controlled in step mode to take measurements while stopped.

Fig. 5 shows the path loss at 24GHz for both LOS and NLOS. As can be seen from the figure, the algorithm gives a good prediction of path loss in both LOS and NLOS environment. The simulation does not have as many fluctuations as the measurement due to the limited number of paths considered. The path loss results are similarly good for the other four frequency bands, not shown here.

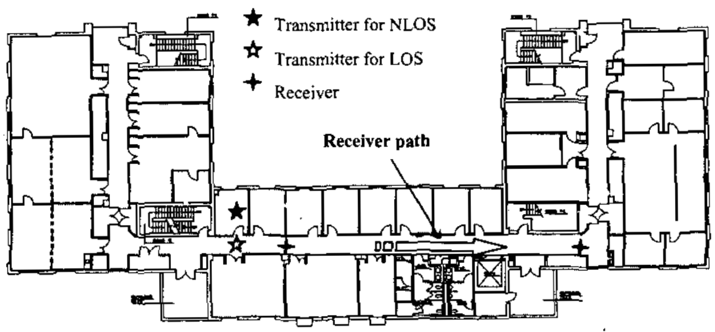

Fig. 4 3rd floor of Caltech's Moore building (Department of Electrical Engineering)

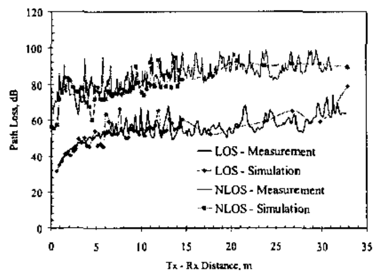

Fig.5 Path loss vs. distance at 24 GHz

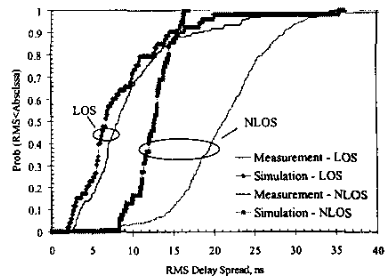

Fig. 6 CDF of RMS delay spread at 24 GHz

Fig. 6 gives the cumulative distribution function of the RMS delay spread at 24GHz for both LOS and NLOS. As can be seen, the simulation is good for the LOS but is not so close in the NLOS scenario. That may be due to the absence of some of the higher order paths in the NLOS model and also because of noise when the signal is quite weak. The power delay profile for NLOS has shown that some delayed paths are missing in the NLOS model presented here. We will show the path loss and RMS delay spread plots for all five frequency bands at the conference. Only the 24-GHz data is given here due to space constraints.

V. CONCLUSION

In this paper, we have developed a combined E/H plane 2D ray-tracing method. This method predicts loss accurately for both line-of-sight and non-line-of-sight paths. In addition, it predicts RMS delay spread for line-of-sight well, but fails for non-line-of-sight. The simulation and measurement were done at five selected frequency bands from 2.4 to 24 GHz.

VI. ACKNOWLEDGEMENT

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