EFFICIENT IMPLEMENTATION OF DETERMINISTIC 3 -D RAY TRACING MODEL TO PREDICT PROPAGATION LOSSES IN INDOOR ENVIRONMENTS

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Abstract - This paper discusses an efficient implementati on of Deterministic Ray Tracing model for indoor wireless propagation and the nth order contribution of reflection components. It is important to characterize the indoor propagation channel to ensure satisfactory performance of a wireless communication system. Ray tracing method is extremely effective in indoor environments for estimating the average propagation loss caused by severe multi path reflections. In this model the dominant rays are calculated using Geometrical Optics implemented by the method of images. Deterministic models are computationally expensive but provide accurate results, which become essential in Indoor Wireless site-specific propagation modeling. A Software package has been developed which performs 3D ray tracing and calculates signal strength variations in a given wireless environment. To validate software results, experimentation at 836 MHz & 1 GHz was carried out in the building of Electrical Engineering Department at UET Lahore. Measured results were mostly found to be in close agreement with the calculated values, proving the validity of the implemented model.

I. INTRODUCTION

Wireless has recently become an increasingly viable option for indoor communication systems. The availability of higher frequency bands in the 900 MHz and 2.4 GHz range has made wireless an attractive option for high bandwidth digital communication applications such as IEEE 802.11, Blue Tooth, Palm Pilot and temporary communication setups. Wireless networks can be particularly advantageous for applications, which require portability, or where installation of wiring is undesirable or impractical. Multipath interference, or interference due to the reception of multiple copies of a signal due to reflections, is known to be a problem in all types of indoor communication channels. At UHF and microwave frequencies, the presence of walls and large objects in rooms makes the indoor multipath environment quite different from most outdoor scenarios. As a result, the study of indoor propagation characteristics has become an area of increased importance.

II. CHANNEL MODELING

In order to evaluate the effectiveness of a given channel coding and processing technique before implementation, some model of the channel must be developed that adequately describes the environment. Such analysis reduces the cost of developing a complex system by reducing the amount of hardware that has to be developed for evaluation of performance. Theoretical models have an added advantage in their ability to reproduce a channel for comparison between various communication strategies, resulting in an accurate measure of relative performance. Indoor channels are highly dependent upon the placement of walls and partitions within the building. In such cases, a model of the environment is a useful design tool in constructing a layout that leads to efficient communication strategies. To achieve this aim, a channel model of an indoor environment must be applied to various layout plans of offices, which will lead to the characterization of design methodologies. Much work has been carried out in measuring the channel in buildings of various layouts, and structural compositions.

Theoretically the solution of Maxwell's equations with boundary conditions derived from the building geometry can be used to calculat e EM wave propagation characteristics. Practically, this approach is not feasible due to its mathematical complexities, which is beyond the power of today's computers. This opens the door for methods that can be used to calculate approximate numerical solutions, ray-tracing being one of these. Ray tracing is successfully used in Optics to model characteristics of various optical systems.

The concept of ray-tracing modelling is based on the fact that high-frequency radio waves behave in a ray-like fashion. Therefore signal propagation can be modelled as ray propagation. By using the concept of ray-tracing, rays may be launched from a transmitter location and the interaction of the rays with the partitions within a building modelled using well known reflection and transmission theory.

Two types of ray -tracing methods – the image method and the brute-force ray-launching method – are being used in the characterization of indoor electromagnetic-wave propagation. For scatters bounded by plane faces it is convenient to employ the image method to mirror the radio wave source at a particular face. The point where the mirror face intersects the line connecting the transmitter image and the receiver is the point at which specular reflection occurs. This method is well suited to radio propagation analysis in the case of geometries of low complexity and where a low number of reflections are considered.

The brute-force ray-tracing method considers a bundle of transmitted rays that may or may not reach the receiver. The number of rays employed and the distance from the transmitter to the receiver location determine the available spatial resolution and hence the accuracy of the model. Ray tracing can be much less demanding of computations than methods based on Maxwell's equations. With the computing powers currently available on personal computers and workstations, the ray tracing approach provides a challenging but feasible method of propagation modeling 1- 2. Reliable site-specific ray-tracing propagation prediction models for each building based on its detailed geometry and construction can be very effective tools in designing indoor communication system.

When a signal is transmitted through or reflected off a wall or a partition, the degree of signal attenuation and the amount of phase change depend on the complex transmission and reflection coefficients, respectively. These are computed from the complex permittivities of the materials that signal rays encounter. Other factors affecting the transmission and reflection of the signal are the angle of incidence and the relative polarization. The complex transmission coefficient is defined as the ratio of the transmitted to the incident electric field strengths and the complex reflection coefficient is defined as the ratio of the reflected to the incident electric field strengths.

Due to the complexities of modeling a dynamic environment using a ray tracing technique, it is only practical to simulate the fading channel of a mobile system by moving either the transmitter or the receiver around the environment. The results of this process may be presented in terms of the signal power that would be experienced by a receiver moving through this environment, or in a more detailed form showing the multi path nature of the environment, and the changing channel impulse response as the receiver moves around the environment. In ray tracing methods, the location of transmitters and receivers are assigned to points referenced by three-dimensional coordinates. The walls, partitions, ceilings and floors in an indoor environment are modeled as plane surfaces of given thickness and permittivity. For simplification, curved surfaces can be modeled by piece-wise planar surfaces. The rays from the transmitter antenna are reflected off walls, partitions, ceilings, floors and tables etc. to arrive at the receiver.

It is evident that in case of indoor wireless propagation the proximity and number of walls, which act as good reflector of electromagnetic energy and also introduce a signal loss and phase change when a ray is transmitted through them, only ray tracing based modeling methods can give a true picture. This certainly requires much work because for any successful ray tracing based software requires the following as minimums inputs: A detailed geometry of the building under consideration.

This geometry must be in three-dimensional coordinates and for image theory based method non-planar surfaces must be broken down in planar segments before they can be inputted to the software. Fortunately, the information about building geometry is mostly available, sometimes in electronic CAD formats and this for almost all practical purposes consists of planar surfaces.

Each wall and partition must be accompanied by its real and complex permitivitivities, because these are used to calculate the complex reflection and transmission coefficients given in [3]. Extensive tables of these values for common building walls and partitions are available in the literature. In case the exact values are not available typical values can give a much better picture compared to classical statistical techniques. In case of outdoor open environment one obstacle that is always present is the ground; this is true for indoor scenarios too. Ground acts as a good reflector and this must be modeled as an infinite plane in case of indoor scenarios. Any energy from the radiating element directed toward the ground undergoes reflection.

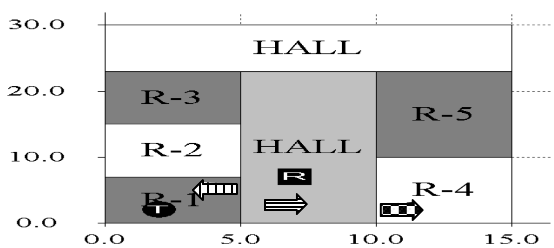
The amount of reflected energy and its direction are controlled by the geometry and constitutive parameters of the ground. In general the ground is a lossy medium whose effective conductivity increases with frequency. Therefore it should be expected to act as a very good conductor above a certain frequency, depending primarily upon its moisture content. To simplify the analysis we will assume that the ground is a perfect electric conductor, flat, and infinite in extent. The same procedure can also be used to investigate the characteristics of any radiating element near any other infinite, flat, perfect electric conductor. In practice, it is impossible to have infinite dimensions but we can simulate (electrically) very large obstacles.

III. SOFTWARE IMPLEMENTATION

The software provides a Graphical User Interface (GUI) for editing and defining 3D building database. For simplicity and efficiency only planar partitions are allowed. Any polygonal shape with n-edges can be entered with the coordinates of its vertices in a CCW direction. Each partition must be defined with a thickness and complex permittivity, which is then used to calculate reflection and transmission coefficients. Two types of studies are supported. The Point Study calculates field strength for only one location of transmitter. The Line Study can be used to simulate a mobile receiver traveling along a given linear path, which is sampled at a user-defined interval. For each study the user is asked to define the number of reflections that need to be considered. The algorithm starts by pre-computing all images and reflection and transmission coefficients of all partitions. This pre-processing is found to give a significant boost to software performance. Ray tracing is done by an exhaustive search of this image tree taking into account decomposition of ray at each planar intersection. First of all contribution of line of sight ray is calculated. This ray is always possible but the number of transmissions it has to go through varies from case to case. It is found from the profiling studies of the software that the maximum time is consumed in calculating intersections, because if we take the brute force approach, for each ray we need to check each partition as a potential transmission candidate. Fortunately, a well known optimization technique from Computer Graphics comes to our rescue. Each partition is accompanied by a cubic bounding box, and actual intersection calculations are done only if the ray passes though the bounding box. This optimization technique enables us to discard most of false targets without incurring the overhead of intersection calculations. The partitions, which pass the transmission test, are then used to calculate the resultant complex electric field value at the reception point. The phasor sum of individual contribution of each successful ray is then used to compute final value of Electric field vector which is then used to calculate received power. In case of line study this procedure is repeated for each point on the specified linear path. The results are then graphically presented to the user. The software also provides the option to export the results to MATLAB for further processing if desired.

IV. SIMULATIONS

The simulation was carried out for three different paths. In the first scenario the transmitter and the receiver were placed in the same room (R -1) and second scenario the receiver was moved in the adjacent room (Hall,) and thirdly the receiver was shifted to the next room (R-4).



Legend

	Starts	Ends
Path 1	(3,3,2)	(2,3,2)
Path 2	(6,3,2)	(7,3,2)
Path 3	(11,3,2)	(12,3,2)

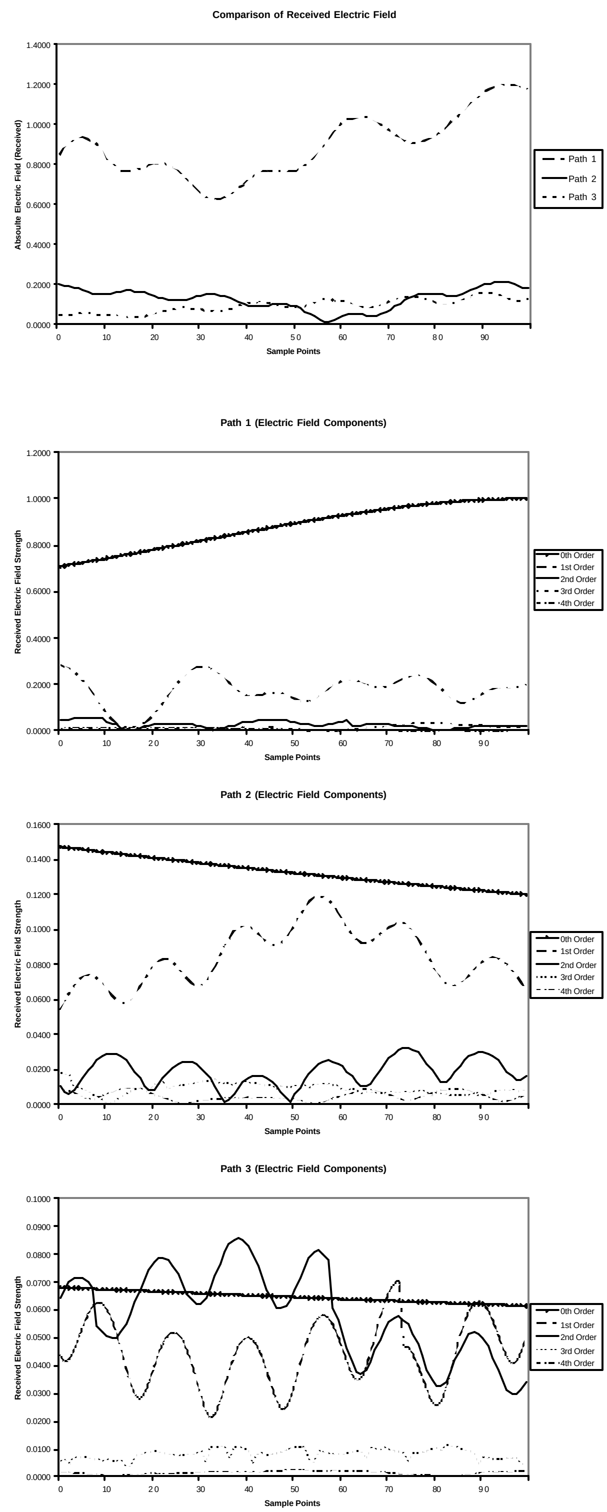


Fig 2

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V. RESULTS

Following are the sample results obtained from our software package named "Ray Tracer 2000". The scenario consists of Communication Lab at UET Lahore with dimensions of 8.23 x 24.7 meters. The number of reflections to be accounted for was set equal to 4, and the number of points (for line study) was set as 100. Average execution time was less than 20 seconds on an Intel Pentium Celeron 1100 MHz processor, with 256 MB RAM.

Simulation Results

Results of three simulations are shown in Fig 2. The three line study paths shown represent real-life scenarios which were intentionally chosen to study the contribution of various order reflections. On Path 1 the transmitter and receiver are in the same room, making the contribution of 0^{th} order line of sight electric field to be the greatest. Along the second path there is one partition between transmitter and receiver and this accounts for a decrease in 0^{th} order field value while the contribution of higher orders gets a boost. Along the third path the contribution of second order reflections even exceed that of 0^{th} and 1^{st} order reflections. The fast fading nature of indoor channel is quite evident from the graph of total electric field strength The variation in relative strength of various reflection orders depending on receiver location and scenario details makes it clear that line-of-sight approximation which is universally used for outdoor environment is no longer valid in indoor case.

Conclusion

The high degree of correlation between the experimental results and calculated values indicate the accuracy and utility of the 3–D Ray tracing in predicting the propagation channel characteristics of indoor wireless environments. We feel that there is lot of work to be done in extending the functionality of the software developed to include the RMSDelay spread, wide band channel characterization, area study and modulation cum coding effects.

VI. FURTHER WORK

The work can be extended to the delay spread calculations, channel equalization and material estimation. Inclusion of diffraction effects in ray tracing calculations there must be a provision to input 3D directional characteristics of antenna, which should be used a direction dependent gain adjustment factor.

VII. REFERENCES

[1] M. C. Lawton and J. P. McGeehan,: "The application of GTD and ray launching techniques to channel modelling for cordless radio systems", in IEEE Proc. Vehicular Technology Conference, VTC'92, Denver, CO, May 1992, pp. 125-130

[2] K. R. Schauback, N.J. Davis, and T.S. Rappaport,: "A ray tracing method for predicting path loss and delay in microcellular environments", in IEEE Proc. Vehicular Technology Conference, VTC'92, Denver, CO, May 1992, pp. 932-935

[3] W. K. Tam & V.N. Tran: "Propagation modelling for indoor wireless communication", IEE Journal of Electronics & Communications October 1995, Vol. 7 Number 5 pp. 224-226

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