

A 3-D Propagation Model Considering Building Transmission Loss for Indoor Wireless Communications

Myung-Sun Choi, Han-Kyu Park, Youn-Hyoung Heo, Sang-Hoon Oh, and Noh-Hoon Myung

ABSTRACT—In the development of a new wireless communications system, a versatile and accurate radio channel for indoor communications is needed. In particular, the investigation of radio transmission into buildings is very important. In this letter, we present an improved three-dimensional electromagnetic wave propagation prediction model for indoor wireless communications that takes into consideration building penetration loss. A ray tracing technique based on an image method is also employed in this study. Three-dimensional models can predict any complex indoor environment composed of arbitrarily shaped walls. A speed-up algorithm, which is a modified deterministic ray tube method, is also introduced for efficient prediction and computation.

Keywords—Ray-tracing, propagation, building transmission loss, indoor.

I. Introduction

Analysis of the electromagnetic wave environment is a prerequisite for efficient wireless communications, and this investigation is successfully done using a simulation technique rather than a measurement of wave strength in a test site. Currently, the ray tracing prediction model based on the uniform geometrical theory of diffraction is considered the most powerful in terms of accuracy and efficiency [1]-[3]. The ray tracing

models for predicting indoor wave characteristics usually employ a ray launching method and an image method, and are limited in their analysis to a pico-cell. For accurate analysis, the outdoor environment should also be included. A wave penetrating buildings from an outdoor source is sometimes too strong and cannot be neglected for the accurate prediction of an indoor electromagnetic environment. Previous studies [4]-[6] cannot predict indoor environments satisfactorily due to an inaccurate analysis of penetration loss. In this letter, transmission loss is analyzed accurately by considering the thickness and material characteristics of building-walls with a window model. This model includes three-dimensional penetrated waves diffracted by the window, and an image method is employed in the analysis. However, the image method has drawbacks in its computation time when the number of building-walls increases. To solve this problem, a deterministic ray tube (DRT) method [7] is modified and employed for the analysis of complex indoor arrangements.

II. Modeling of Indoor Structures

All of the indoor walls and furniture, such as desks and filing cabinets, are assumed to consist of flat rectangular surfaces. Unlike previous simulation programs [1]-[4], the indoor walls do not need to be perpendicular nor parallel to the ground plane. Then, the computer program has information on edge coordinates and material composition. The material characteristics of walls are usually represented by permittivity and conductivity, and reflection and diffraction coefficients are computed using those parameters. These coefficients are stored for each wall with its coordinate as input variables for the computer program. Figure 1 shows a simplified indoor model used for the computer program, which consists of walls, doors, and windows for a two-story building. Walls in the figure have

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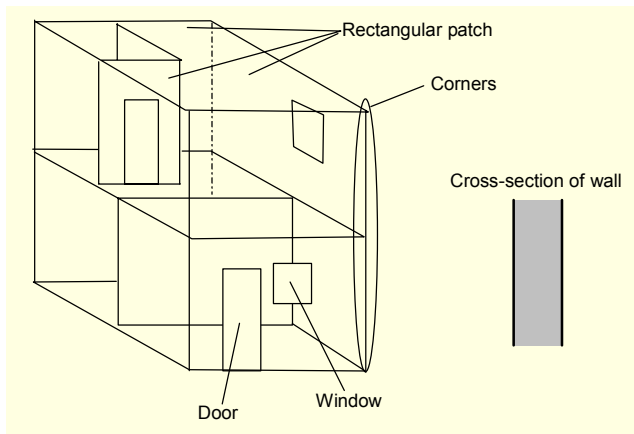


Fig. 1. Modeling of indoor structures.

thickness, and the characteristics of penetrated waves through the walls are analyzed using the simulation program.

III. Modified Deterministic Ray Tube Algorithm

A scattering process composed of reflections and diffractions is performed by the well-known image method, and it constructs a 'ray image tree' [7], which is generated automatically for given positions T_x , R_x , and walls. The DRT method [7] to reduce unnecessary images generates reflection and diffraction ray tubes for a given source and considers only the reflected and diffracted rays that exist within each ray tube. However, in extending to three dimensions, this method develops a problem in that the shape of the ray tube becomes a polygon. In other words, depending on the three-dimensional position of the transmitting source and shape of the object, the ray tube should have a variable shape. This variable shaped ray tube is called a 'polygon ray tube'. Finding walls in the polygon ray tube and a reflection point is so difficult and complex that the computing time becomes unreasonably long.

In this letter, rectangular ray tubes instead of polygon ray tubes are proposed to eliminate unnecessary images. Using rectangular ray tubes, we can find the wall located in a ray tube and know if reflection points belong to the wall or not by simple computation. Figure 2 shows the way to generate a rectangular ray tube. Wall V exists within the ray tube of image i , so that the next reflection image by image i should be generated by this wall. For generating the ray tube of image j , first we obtain overlapped area W by projecting reflection wall W of image i to wall V . Then, we can obtain the ray tube of image j by generating the rectangular ray tube containing this overlapped area. At this point, all corners of two walls are projected to one plane, so that the process to get the overlapped area and to generate the rectangular ray tube is

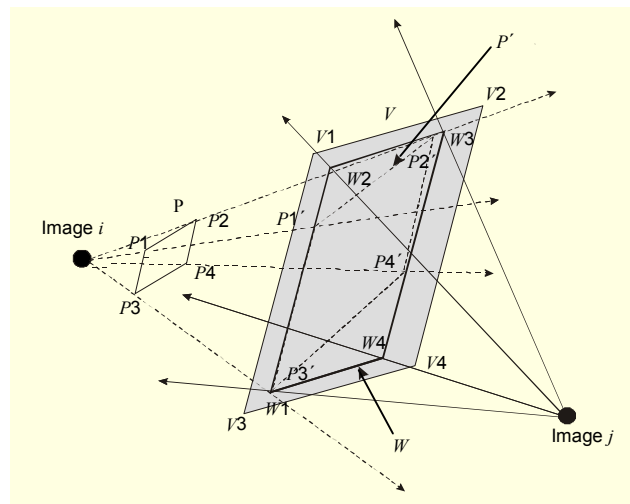


Fig. 2. Generation of the rectangular ray tube.

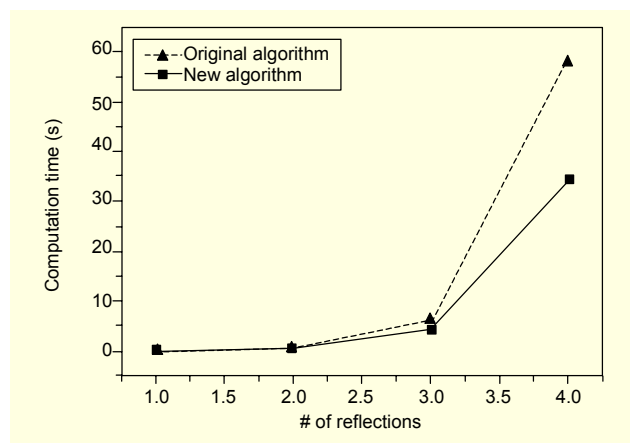


Fig. 3. Computing time according to the number of reflections.

done simply by comparing computations. Figure 3 shows the degree of shortened computing time by this method. The computing time is measured assuming a three-dimensional indoor environment with 50 walls.

IV. Building Transmission Loss

The thickness of the walls and the diffraction by windows must be considered to accurately analyze the transmission loss in buildings. In other words, the images of reflection/diffraction for the window, as well as the images for the walls, are considered to reflect the effect of a window. To verify this analysis, we compare the predicted transmission loss with measured data [8]. Figure 4 shows the building structure to be measured. The material of the inside wall to face the passage is a concrete wall containing a door made with wood. The outside wall contains windows with metal frames and three concrete pillars between each window. A more detailed description of the measurement

environment is presented in [8]. Figure 5 shows the results of comparing measured data with the predicted results between the measurement points O_1 and O_2 . A dotted line is another predicted result by the Finite Difference Time Domain (FDTD) ray-tracing included into the analysis [4]. The main causes of error are thought to be due to reflection by the ground not being considered, or the reflected ray by nearby buildings raising the received signal strength. Table 1 shows that the error by the proposed model is a little smaller than that by the FDTD ray-tracing method. Considering that the FDTD ray-tracing method is a full-wave analysis method, the proposed model can be thought to predict accurate results comparatively.

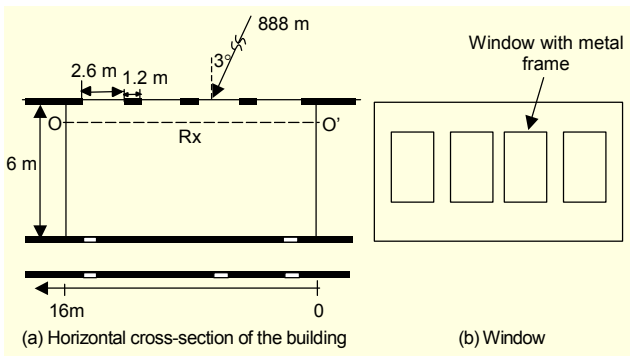


Fig. 4. Structure of the building to be measured.

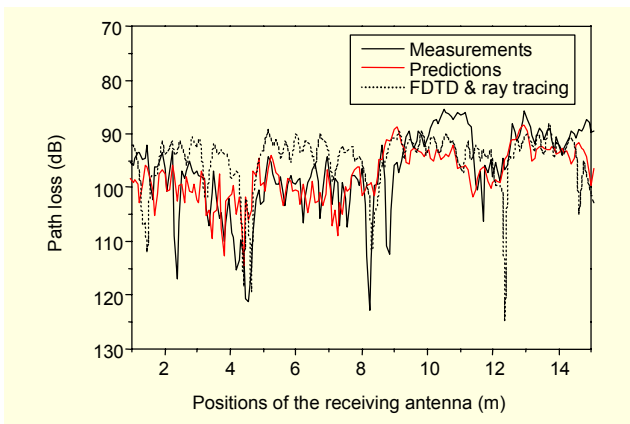


Fig. 5. Comparison of predicted and measured data.

Table 1. Errors of the two methods.

	Mean error	Std. deviation	RMS error
Proposed model	-1.02 dB	6.46 dB	6.52 dB
FDTD & ray tracing model	2.03 dB	7.74 dB	7.99 dB

V. Conclusions

In this letter, a new indoor propagation model using ray

tracing based on an image method is proposed. This model considers building transmission loss for an accurate prediction in the case where the transmitter antenna is located outdoors. We utilize the 3-D propagation model by the image method and employ the modified DRT method to improve the computation time, which increases exponentially as the number of walls increases. The proposed model can analyze the nearby outdoor propagation environment as well as the indoor one, and the accuracy of its wall transmission loss predictions is comparable to a full-wave solution, the FDTD ray-tracing method. The error performance of the proposed method is very good compared with other propagation models. The proposed method is expected to be used for the design of wireless networks in pico-cells.

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