Outdoor/Indoor Propagation Prediction for Complex Wall and Window Structures Using Ray-Tracing Models

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***Abstract*—A new integrated ray-tracing code for propagation prediction in urban environment is developed. Besides the computationally efficient core engine that is based on the triangle and rectangular digitization of the propagation environment (hence eliminating the need for the time consuming search algorithms), new indoor and indoor/outdoor features such as reflection and transmission through complex walls and diffraction effects from windows and metal framed structures are also included in the new code. The accuracy of each of these components is validated experimentally and results from the integrated code will be presented and discussed in the conference.**

Keywords-propagation; complex wall structure; window structure; ray-tracing; FDTD

I. Introduction

Propagation prediction using ray-tracing method has been widely used [1-4]. Ray-tracing method can provide good results in many cases, e.g., for outdoor environments where building walls can be approximated as interfaces between two dielectric media. It is also efficient when advanced acceleration methods are used. For more complicated cases, for example, the transmission through walls with complex structures, or through windows with metal supports or frames, however, brutal implementation of ray-tracing algorithm will be inefficient because there are too many rays to be traced and accounted for.

Recent studies have suggested some new methods for addressing walls of complex structures. Holloway, et al., proposed an equivalent three-layer slab model based on the homogenization technique [5]. The dielectric parameters of the layers are dependent on the angle of incidence. For windows with metal frames, our group developed an equivalent ray-optics model, extracted from FDTD simulations, for realistic metal-framed structures [6].

This paper proposes a ray-tracing procedure that takes all these recent developments into consideration and helps develop some guidelines for the prediction of indoor/outdoor transmission. The core of the proposed ray-tracing scheme employs the rectangular and/or triangular grid method that has been proved to be computationally very efficient [7-9]. The addition of the recently developed new features including the effect of the complex walls and window structures is expected to improve the accuracy and broaden the application of the presently available propagation prediction codes.

II. Metal-Framed Window Structures

Window structures are very common in modern buildings. Fig. 1 (b) shows a typical window structure with metal supports. Measurements show that the penetration through windows is on the average 6 dB more than that of other walls. Due to the complex structure of the windows, however, it is difficult to analyze the penetration fields. Using FDTD, the complicated electric field penetration pattern through the window in Fig. 1(b) is shown in Fig.1(a). It can be seen that the electromagnetic field strength does not monotonically decay along the direction of propagation. Instead, a diffraction pattern is generated and a new model for describing this transmission through windows needs to be developed.

In [6] we proposed a model that can be used in our existing ray-tracing computer codes. The main idea is to break the whole window structure into elementary blocks as shown in Fig. 2. The diffraction pattern of the single block is then calculated using FDTD and the equivalent ray model is extracted. The ray model consists of a number rays with magnitude and phases determined by the FDTD results. It is shown that using superposition method, the total electric field due the whole window structure can be constructed by adding the electric fields from these single building blocks.

Fig. 3 shows the electric field along a line parallel to the window structure and at a distance of 20 wavelengths away. The obtained results from the superposition of elementary blocks of the single window model and the FDTD simulation of the entire structure composed of five window blocks are shown. It can be seen that using the single window building block generally provides good results, particularly as far as the main feature of the transmission pattern is concerned. When the numbers of the equivalent rays increases, the obtained ray tracing results will be even more accurate compared with the FDTD results.

Characteristics of the model were also examined for varying window sizes, different window frame shapes, and oblique angles of incidence. The ray-tracing method was also

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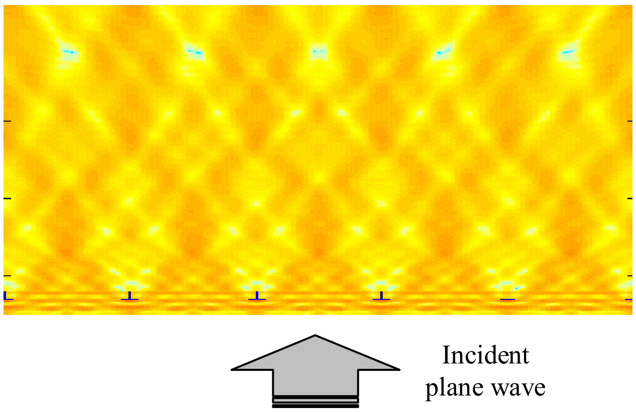
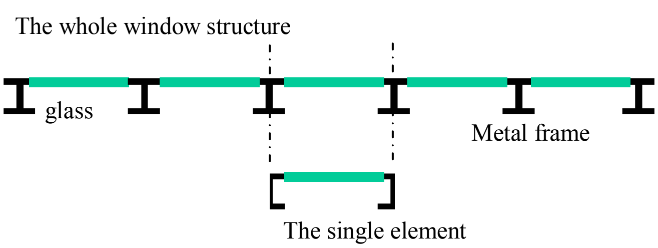
compared with the traditional experimental method, which was implemented by building a scale-model test set in an indoor antenna range. The measured results agreed quite well with the calculated results from the ray-tracing method, thus validating the accuracy of the developed model.



(a)

(b)

Figure 1. (a) Windwo structures with glass and I-shaped metal frames. (b) Plane wave incidence and penetrated electric field through metal framed-windows.



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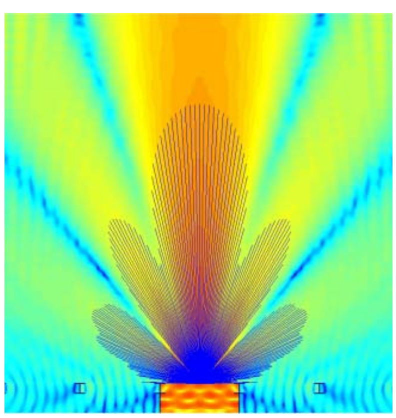


(b)

Figure 2. (a) The elementary window block, and (b) the electric field distribution

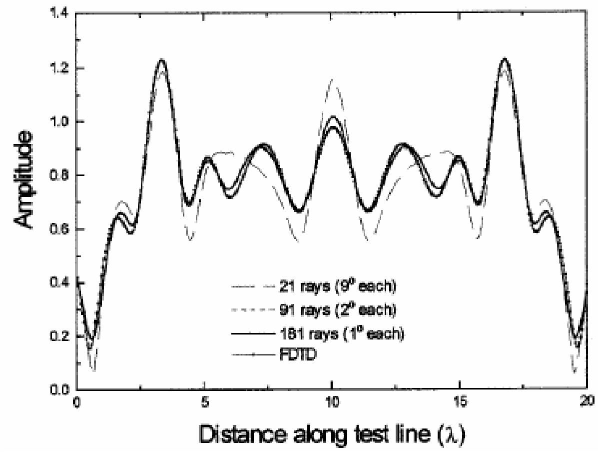


Figure 3. Comparison of the FDTD results and the ray-optics results. It can be seen that as the number of rays increases, the accuracy increases.

III. COMPLEX WALL STRUCTURES

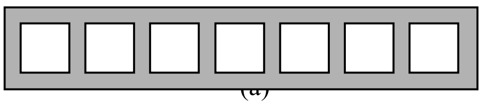
For the complex wall structures it was shown that (see Fig. 4) that resonance will happen, leading to total transmission at some particular angle of incidence or frequencies [10]. Fig.4 (b) shows the reflection and transmission coefficients for the complex walls and the solid slab walls for TE plane wave incidence. It can be seen that the total transmission (or zero reflection) occurs at the angle of incidence around 83° for the complex wall. It should be noted that no total transmission happens for the case of solid slab walls.

Complex wall structures are hence expected to give different field distributions from that of simple slab wall structures. For a realistic floor plan as shown in Fig. 5 we calculated the power distribution also using FDTD. It is found that the power coverage between the complex and simple slab wall structures is different by as much as 40% to 50% [10]. To examine the fading statistics, the mean values of the Rician *K*-factors are extracted from the FDTD results. It is found that the complex wall structure gives larger *K*-values than the slab walls by around 3 to 5 dB. It is also found that the effective approximation of the complex wall using one-layer slab wall does not give good results and more accurate models are needed for the ray-tracing algorithm.

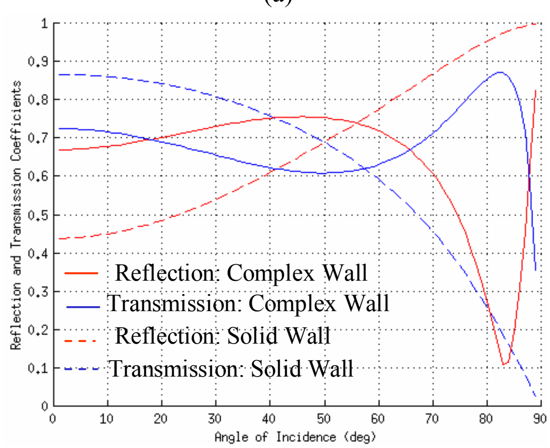
IV. THE NEW RAY TRACING MODEL

For indoor/outdoor propagation predictions, it is common to have window or complex wall structures as the indoor/outdoor interface. We propose a new ray-tracing model that takes the effects of the window and complex wall structures into account.. The core computational engine for the proposed ray tracing model, however, is based on the two space division methods that we have implemented and described in earlier publications [8,9]. These methods proved to be very accurate and equally important resulted in significant improvements in the computational efficiency. In both the indoor and outdoor communications cases, the simulation results agreed very well with measured values. Specifically, for the outdoor propagation, Fig. 6 shows comparison between the simulated results measured data in Munich City, Germany [7]. These results confirm the accuracy of the proposed method which has the additional advantage of being highly computationally efficient.

For the indoor propagation environments, we compared the simulated results with measured data carried out on 2nd floor of the POST building at University of Hawaii. Fig. 7.shows these results and as it can be seen, the error standard deviation between measured and simulated results are less than 3.0 dB. With this confidence in the accuracy and computational efficiency of all the developed components of the new code, efforts are now underway to integrate these capabilities in a uniform accurate and highly efficient channel modeling code for wide variety of propagation environments including outdoor/indoor environments. Results from the overall integrated code will be presented in the conference.



(a)



(b)

Figure 4. (a) Complex wall structure, and (b) the reflection and transmission coefficients for the complex wall and solid wall are compared.

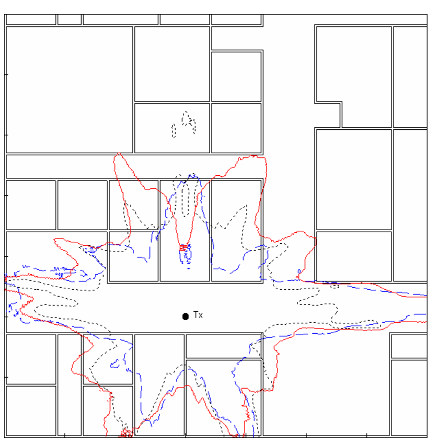


Figure 5. Comparisons of power patterns between the complex (solid line), slab walls (dashed line), and singl-slab effective walls (dotted line).

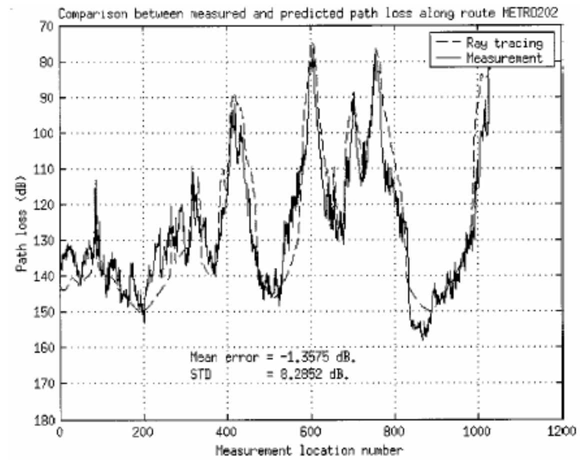
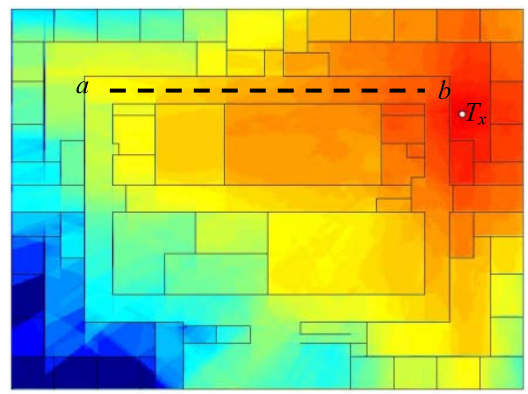


Figure 6. comparison of the measured and simulated path loss along route MERO202 in Munich City, Germany.



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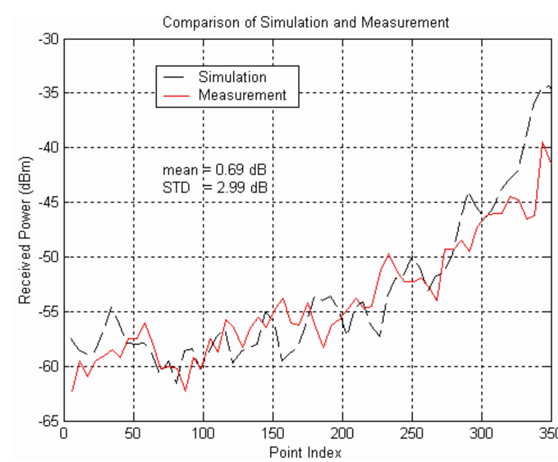

(b)

Figure 7. Power distribution on a floor of an office building. (a) Power distribution calculated using ray-tracing method, and (b) Comparison between simulated and measured results along line *ab*.

V. CONCLUSION

The various components of a new integrated channel modeling and propagation prediction code are described. Besides the computationally efficient core engine of this code that is based on triangle and rectangular digitization of the propagation environment, the new code includes capabilities that address challenging indoor/outdoor communication environments. This includes accurate modeling of transmission through windows and metal-framed structures, and the detailed simulation of the transmission though wall of complex geometries. The accuracy of each of these components was validated experimentally and results from the overall integrated code will be presented and demonstrated in the conference.

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