3-D Wave Propagation Simulation in Complex Indoor Structures

Farshid Aryanfar* and Kamal Sarabandi
faryanfa@umich.edu, saraband@eecs.umich.edu
Radiation Laboratory, EECS Department, University of Michigan
Address: RADLAB, 1301 Beal Ave., Ann Arbor, MI 48109, USA

I. Introduction

Modern wireless radio systems like public mobile cellular services (GSM or CDMA), PCN, DECT, wireless LANs, etc are established in different operating frequency bands according to their specific applications. For new service deployments and expansion or improvement of the existing systems, accurate path loss and power delay profile prediction in different environments is important for specifying system parameters.

Recently, wave propagation prediction algorithms based on site-specific deterministic models, quasi-optical ray tracing and higher order electromagnetic wave propagation models have been developed. Examination of reported wave propagation algorithms shows that a better agreement between prediction and measured propagation characteristics requires both a more accurate model of environment and more rigorous electromagnetic formulation. Many of the existing algorithms are incapable of handling complete 3-dimensional environment and are inappropriate for complex indoor environments such as parking structures that include vehicles. In this investigation a full 3-D wave propagation model is developed that accounts for wave reflection, refraction, diffraction and absorption and allows for specifying the details of scatterers in the environment. The electrical properties of the objects can also be specified. For a parking structure an object with a very complex geometry such as vehicles, pillars, etc. are easily definable.

The determination of path loss and power delay profiles is made on the basis of the vector summation of rays at the receiver through various paths (e.g. reflected, transmitted, diffracted and any combination of them). Geometrical optics (GO) and a modified uniform theory of diffraction (UTD) are applied for the calculation of each ray contribution. Relative complex dielectric permitivity, conductivity and material thickness are considered as the main defining parameters of any reflecting surface and diffracting wedge. Unless specified otherwise it is assumed that all reflecting surfaces are planar and smooth. The surface roughness effects can be included using a probabilistic model for the surface profile. Antenna effects such as directivity and the polarization can be chosen arbitrarily. Reflection, transmission and diffraction coefficients used in our model are in matrix form and take the polarization of the fields into consideration.

II. Wave Propagation Simulator

The simulator consists of two discrete computer codes, environment modeler and ray tracing engine. The flowchart of the ray tracing engine is shown in Figure 1. Any arbitrary structure and objects can be defined using the environment modeler and it exports the data for the ray tracing engine. The software outputs are coverage, path loss, power delay profile, and angle of arrival for specified receiver(s) position based on the structure data imported from environment modeler and the electrical properties of the objects.

III. Simulation Results

There is always a trade off between simplification of the environment model and the accuracy of predicted results of wave propagation. In order to investigate this, wave propagation in a parking structure with two different models for vehicles are studied. As shown in Figure 2, the simple model is just a simple box and a complex model is made up of 77 pieces of metal and absorbers that approximately shape a car. For a typical parking structure shown in Figure 3, using simple and complex models for the cars, the signal coverage is calculated. Figures 4 and 5 show the simulated results. Difference between the predicted path-losses for these two cases is shown in

0-7803-8302-8/04/$20.00 ©2004 IEEE

Figure 6. As shown the difference varies from -40 to +40 dB with maximum values located in the shadow regions.

As the rays (waves) are trapped in covered parking lot the number of reception paths for each receiver (about 20 reception paths in average for the scenario in Figure 3) is far more than outdoor cases. This decreases the importance of the diffracted rays from edges. For the simple car model case the effect of diffraction is investigated and shown in Figure 7. Table I shows the simulation details and running time for all cases.

Table I. Simulation parameters

	Number of objects/receivers	Angular resolution (degree)	Diffraction	Mean of Path-Loss (dB)	STD of Path-Loss (dB)	Run Time[1] (minutes)
Simple model	24/3400	1	No	-73.87	13.19	8
Complex model	882/3400	1	No	-72.69	10.23	12
Simple model	24/3400	1	Yes	-72.03	10.18	58

1. On a PC with PIII, 900 MHz processor and 512 MB RAM for Max path-loss = 120 dB.

From Table I and Figures 4-7 it can be concluded that for closed indoor areas like covered parking structures with many scatterers modeling the environment with more details is beneficial because it improves the accuracy of the simulated results while simulation time is not significantly increased. But considering diffraction may not be useful as it is very time consuming and does not have a major impact on the total predicted result because of extreme multi-path effects.

References

[1]. F. Aryanfar, Il-Suek Koh, and K. Sarabandi, "Physics based ray-tracing propagation model for sub urban areas", IEEE Antennas and Propag. International Symp., vol. 4, pp.903–906, June2003.

[2]. F. Aryanfar and S. Safavi-Naeini, "Electromagnetic modeling of radio-wave propagation in micro- and pico-cellular environments", IEEE Antennas and Propag. For Wireless Communication Conf., pp.25–28, Nov. 1998.

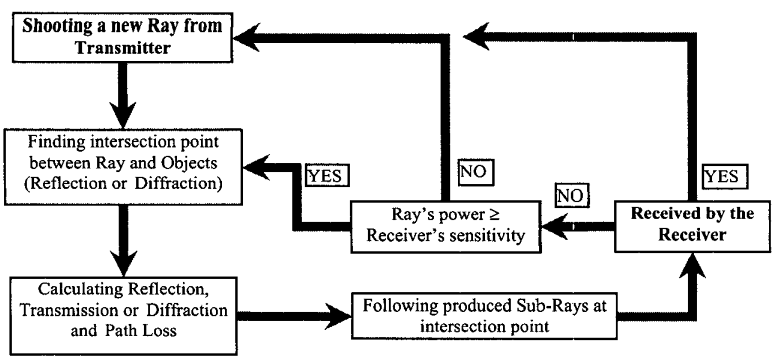

Figure 1. Ray-Tracing Engine Flow Chart

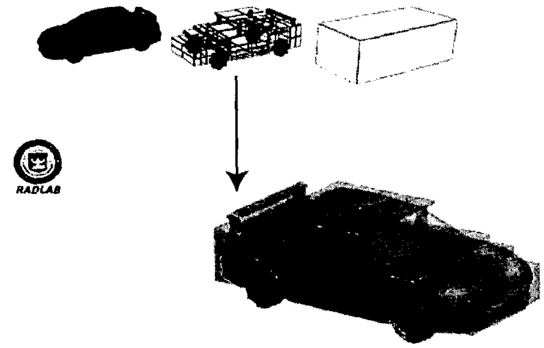

Figure 2. Simple and Complex Car Models

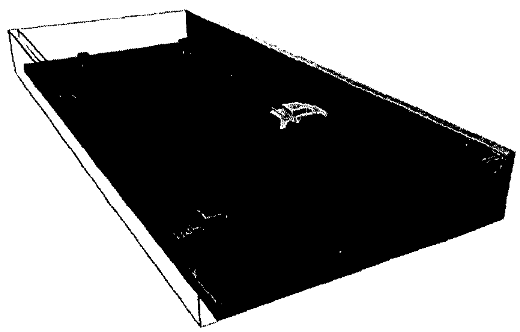

Figure 3. 3-D view of covered parking lot

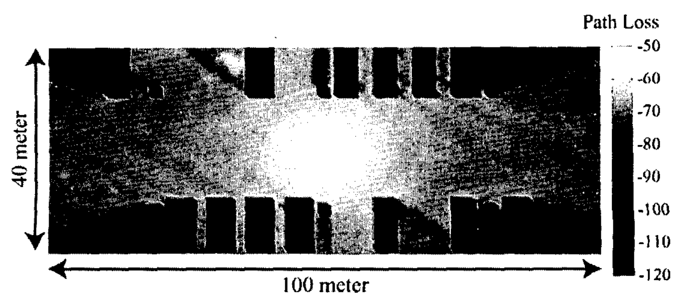

Figure 4. Simulated path loss using simple car models

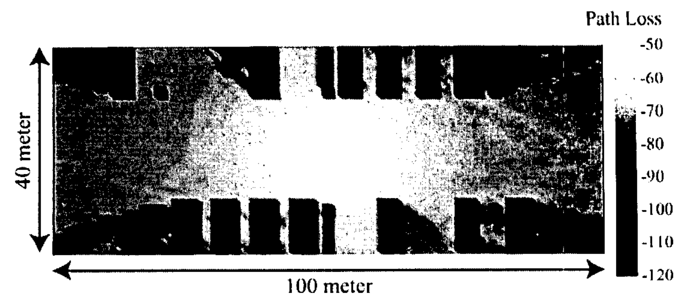

Figure 5. Simulated path loss using complex car models

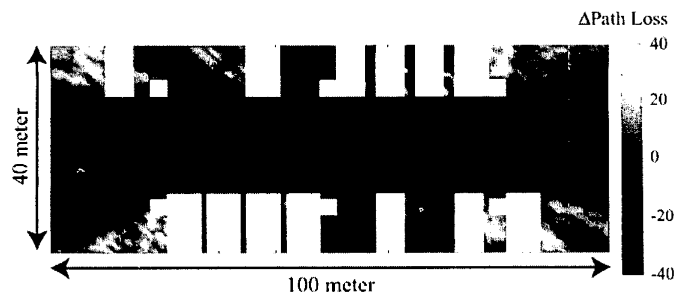

Figure 6. Path loss difference due to car modeling

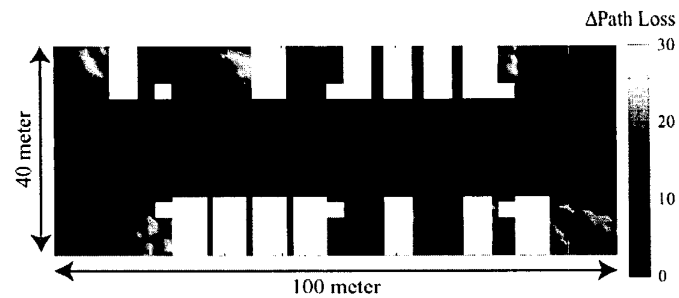

Figure 7. Path loss difference due to diffraction using simple car models