RESEARCH IN SITE-SPECIFIC PROPAGATION MODELING
FOR PCS SYSTEM DESIGN

Scott Y. Seidel, Kurt R. Schaubach, Thomas T. Tran, and Theodore S. Rappaport
Mobile & Portable Radio Research Group
Virginia Polytechnic Institute and State University
Blacksburg, VA

Abstract

This paper describes some of the work being done for site-specific propagation modeling at the Virginia Tech Mobile and Portable Radio Research Group (MPRG). Ray tracing and diffraction propagation models that utilize site-specific building information are used to predict path loss and multipath power delay profiles.

1. Introduction

Propagation experiments throughout the past few years have provided some basic models which give insight into the statistical nature of signal strength and multipath propagation in microcellular environments. Models such as those presented in [1]-[4] have indicated that depending on the physical surroundings of the communication path, signal strengths and multipath delay spreads can vary by orders of magnitude within a relatively small area of a few hundred meters. The predictability of channel behavior can be improved by incorporating a greater quantity of site-specific data in the propagation model.

Site-specific propagation prediction and installation tools offer promise and are likely to find widespread use. The instantaneous signal level is much less important in emerging wireless systems that use spread spectrum and other wide bandwidth modulation techniques. The inherent frequency diversity of wide band transmissions allows system designers and installers to concentrate on local average signal levels, which are subject to variations induced by the physical dimensions of objects in the channel. The ability to concentrate on local averages rather than instantaneous signal levels allows site-specific propagation models to operate on a segmented model of the coverage area, where each segment of an area spans several wavelengths in any direction.

Physical databases such as terrain maps, building blueprints, aerial and satellite data of building locations are widely available. Increased computing power will let system installers integrate detailed physical descriptions of the wireless environment with new site-specific propagation models.

This paper shows that by integrating site-specific map information of the physical environment with innovative modeling techniques based on ray tracing and diffraction, good agreement between measured and predicted path loss and multipath profiles can be obtained. Recent efforts in our approach to predict site-specific propagation in microcellular environments are described. Results of the site-specific propagation prediction based on ray tracing and diffraction are presented.

2. Microwave Multipath Measurements

Spread spectrum measurement systems can be used to estimate the propagation channel impulse response. The main advantage of a spread spectrum receiver system is that wide bandwidth impulse response estimates may be measured with a dynamic range that is comparable to narrow band measurement systems. This is accomplished by de-spreading the probing signal before detection by a narrow band receiver. The MPRG utilizes a continuous spread spectrum channel sounder for propagation measurements in the UHF and low microwave region. The chip rate is 240 MHz, allowing a multipath time resolution of less than 10 ns.

The MPRG has several different types of antennas that can be used to measure propagation characteristics in microcellular and in-building environments. Omni-directional vertically polarized disc-cone antennas are used for basic channel sounding. Directional horn antennas up to 26.5 GHz and circularly polarized helical antennas can be used to investigate the effects of directivity and polarization on radio propagation characteristics.

3. GIS in Site-Specific Propagation Prediction

For reliable prediction and design of mobile communication system performance, environmental factors need to be accounted for with as much detail as possible. Such information includes buildings as well as significant terrain features: GRASS (Geographical Resources Analysis Support System) and AutoCAD can be used as database managers for site-specific propagation prediction. GRASS is a GIS (Geographical Information System) software used to store and manipulate spatial data such as terrain surface maps, while AutoCAD is used to store the building layouts. Both tools are used for data display, manipulation, and analysis.

Computer databases of terrain and buildings for microcellular environments in the US are available through the US Geological Survey (USGS) and other sources. Figure 1 shows a two-dimensional view of downtown Washington, D.C. in GRASS with street and building data overlaid on top of terrain. The building height information is determined by photogrammetric techniques [10]. Each building within the database can be assigned reflection and transmission losses according to the building material or by user specification. Thus, we have developed the framework to incorporate readily available environment information, handle large amounts of that information within the propagation prediction tool, and utilize the information to more accurately predict the propagation.

Computer programs that implement ray tracing and diffraction models in [5], [6] have been written to accommodate the general GRASS building overlays. This model predicts path loss using Fresnel-Kirchoff diffraction theory and ray tracing in two dimensions. This model is described in more detail in [6], and prediction results are given in Section 5.

4. Ray Tracing in Three Dimensions

Large scale geometry (building and wall height, location, and orientation) dominates the average path loss of wideband signals and slow fading is attributed to large scale environmental factors.

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such as building location and geometry. The time dispersion of a wideband channel can be attributed to the location of the scatterers.

A three-dimensional ray tracing propagation model uses geometrical optics to trace the propagation of direct, reflected, transmitted and scattered fields. By tracing “tubes” of energy from a point source, the physical process of a radio wave being launched from a point source is closely modeled. Although it appears at first that this method is much less computationally efficient than image theory, it is much more flexible since different propagation modes can be handled easily [7], and ray tracing acceleration techniques coupled with parallel computing are employed to drastically reduce computational requirements.

The propagation of energy from the transmitter to the receiver is modeled by various modes such as direct, reflected, transmitted, and diffusely scattered paths as shown in Figure 2. Direct (line-of-sight) rays and specularly reflected and/or transmitted rays exhibit a $1/d^2$ power dependence according to Friis free space transmission, where $d$ represents the total ray path length. The diffusely scattered field, comprised of the path segments $s_1$ and $s_2$, exhibits a multiplicative dependence given by $1/(s_1s_2)^2$ which is due to the additional spreading loss the ray experiences after re-radiation from the scattering surface. The scattered energy at the receiver due to a specific object in the channel is modeled as the superposition of the scattered energy carried by all ray tubes that intersect the object and scatter energy toward the receiver. In microcellular radio channels, there are many ninety degree corners around a city block. In these heavily shadowed environments, diffraction can be a significant contributor to the received signal strength [5], and is also included in the model [8].

because the program predicts mean field strength (path loss) as influenced by the local variations in site-specific geometry over several wavelengths. Diffraction is included via a wedge diffraction model in [9]. For non-diffracted rays, the field amplitude of the $i^{th}$ ray at the receiver is given by

$$E_i = E_{0i} \int f_i \alpha_i \beta_i \gamma_i \delta_i \gamma_i \delta_i \gamma_i \delta_i$$  \hspace{1cm} (1)

Table 1: Summary of the variables used to describe the ray tracing propagation model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{0i}$</td>
<td>Field amplitude radiation pattern of the antennas</td>
<td></td>
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<tr>
<td>$\alpha_i$</td>
<td>Path loss distance dependence for the $i^{th}$ multipath component</td>
<td></td>
</tr>
<tr>
<td>$\beta_i$</td>
<td>Path length [meters]</td>
<td></td>
</tr>
<tr>
<td>$\gamma_i$</td>
<td>Path loss for scattered rays</td>
<td></td>
</tr>
<tr>
<td>$\delta_i$</td>
<td>Angle of $i^{th}$ scattered ray with the specular direction [rad]</td>
<td></td>
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<tr>
<td>$\epsilon_i$</td>
<td>Reflection and Transmission coefficients</td>
<td></td>
</tr>
<tr>
<td>$E_i$</td>
<td>Field strength of the $i^{th}$ multipath component [V/m]</td>
<td></td>
</tr>
<tr>
<td>$E_0$</td>
<td>Reference field strength [V/m]</td>
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A computer program has been written to implement an automated ray tracing tool to find each ray path by which significant levels of energy radiated from the transmitting location reaches the receiving point. The ray tracing is accomplished by an exhaustive search of a ray tree accounting for the decomposition of the ray at each planar intersection. After the direct path has been checked, the program traces a ray from the source in a predetermined direction and detects if an object intersection occurs. If no intersection is found, the process stops and a new source ray is initiated. Once the program determines that an intersection has occurred, it then checks to see if a reflected, transmitted, or scattered ray has an unobstructed path to one of the receiving locations. After checking for ray reception, the program divides the source ray into a transmitted and reflected ray, which are then treated in a similar fashion as the source ray. This recursion continues until a maximum number of specified ray levels is exhausted or the energy in the ray falls below a user-specified threshold. Scattered rays are not traced recursively since the amplitudes of these rays decrease rapidly with distance. More details on the ray tracing method are given in [7],[8].

5. Results

The accuracy of any propagation model can only be determined by comparison of measured and predicted propagation data at specific locations. Figure 3 illustrates several locations where measurements and predictions were made at 1900 MHz with the spread spectrum system described in Section 2. For the measurements, the transmitter was placed behind Burruss Hall in a location typical of a microcell base station. An omnidirectional discone antenna was placed at a height of 7.6 meters and had an ERP of 1 Watt. The receiver was moved to several locations as shown on the figure. These locations were selected to provide both line-of-sight and obstructed topographies. The receiver used an omnidirectional antenna mounted at a height of 1.7 meters.

Figure 4 illustrates a representative comparison of measured and predicted power delay profiles. The three-dimensional ray tracing propagation model described in Section 4 was applied here. For the predictions, a simple 12 dB reflection loss, regardless of the incidence angle or building material, was assumed. Additionally, a 9 ns base-width Gaussian pulse was convolved with the predicted impulse response for comparison purposes. The profile in Figure 4 was generated for the measurement location adjacent to Hancock Hall. As can be seen in the figure, the line-of-sight component is accurately predicted and the amplitudes and time delays of several
Figure 3: Three dimensional AutoCAD building database for the academic quad on the Virginia Tech campus. The circles represent locations where 1900 MHz microcell measurements were made.

specular reflections are also identified. The measured path loss and rms delay spread was 30.8 dB above 1 meter free space path loss and 23.2 nanoseconds, respectively. The predicted results were 33.1 dB and 44.8 ns respectively. Figure 5 shows a scatter plot of measured and predicted path loss for the four measurement locations depicted in Figure 3 and four locations from another part of campus. The predicted path loss is given for both the three-dimensional ray tracing model and the diffraction model. The diffraction and two-dimensional ray tracing model [6] used a 12 dB reflection loss for incidence angles within 45 degrees of reflection surface normal and a 6 dB reflection loss for incidence angles greater than 45 degrees from the surface normal. The standard deviation of path loss error is 4.2 dB for the three-dimensional ray tracing model, and 4.8 dB for the diffraction model for the eight locations where wide band measurements were made. The delay spread prediction had considerable error in many locations due to multipath components arriving at long delays which heavily influence the delay spread, even though these components are relatively low in amplitude.

Measured Impulse Response

Predicted Impulse Response

Figure 4: Measured and predicted power delay profiles for the Hancock measurement site.

Figure 6 shows measured CW signal strengths throughout a coverage area on the Virginia Tech campus at 914 MHz. The data are grouped in 5 dB ranges of signal strength from -65 dBm to -80 dBm for a 1 Watt transmitted power. The transmitter height was 16 m and the receiver height was 2 m above ground with omni-directional antennas. The predictions using the diffraction and two-dimensional ray tracing model [6] for these same campus locations are indicated in Figure 7. Notice that the predictions can track the path loss variations throughout the coverage area.

6. Conclusions

This paper has described the recent efforts of the Mobile and Portable Radio Research Group in the area of microcellular site-specific propagation prediction. Ray tracing and diffraction software have been shown to give good agreement with measured propagation results for several test cases on the Virginia Tech campus.

We have demonstrated how ray tracing can be implemented in a computer program to predict propagation based on site-specific information. Site-specific propagation prediction appears to hold promise for providing significant improvements over current models in predicting radio coverage for microcellular environments.

7. References

Figure 6: Measured CW signal strength throughout the academic quad of the Virginia Tech campus. The transmitter was located on the top of Whittemore Hall and can be located in Figure 3.

Figure 7: Predicted CW signal strength for the measurement locations specified in Figure 6. The transmitter was on the top of Whittemore Hall and can be located in Figure 3.