CHAPTER 4

CHANNEL CHARACTERIZATION AND PROPAGATION MODELS FOR WIRELESS COMMUNICATION SYSTEMS

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INTRODUCTION

A wide variety of radio propagation models for different wireless services that specifically address varying propagation environments and operating frequency bands are generally known (Pahlavan et al. 1995; Jakes 1974). A large number of propagation prediction models have been developed for various terrain irregularities, tunnels, urban streets and buildings, earth curvature, etc. (E. Vehicular Technology Society 1988; Lee 1989; Parsons et al. 1998). For propagation models addressing satellite communications systems, on the other hand, different types of issues including rain attenuation and atmospheric effects are routinely considered (Dissanayake et al. 1997). The level of sophistication in the development of these models also depends on the longevity of the related technology. For example, the importance of developing propagation models suitable for satellite communications, and in particular the development of reliable models for rain attenuation and other atmospheric impairments along earth-satellite paths, has long been recognized; and extensive research activities have been focused on addressing these effects (Capsoni et al. 1987; Stutzman 1995). With the development of new satellite services incorporating very small aperture terminals (VSAT) and ultra small aperture terminals (USAT) in the Ka-band (20-30 GHz) frequencies, more recent research efforts in this area have focused on refining available propagation models to account for and accurately predict the total propagation link margin that includes other propagation impairments such as cloud attenuation, gaseous absorption, and low-angle fading. European and U.S. agencies are compiling several databases that should enable the evaluation of propagation models that attempt to combine different propagation effects (Dissanayake 1997). These research activities and available results should also be useful in addressing the needs of new emerging high frequency and point to multi-point terrestrial wireless communication systems such as the local multi-point and point-to-point distribution systems (LMDS and PPDS, respectively) and wireless local area networks.

With the phenomenal growth in mobile and portable terrestrial wireless communication systems, and due to their potential utilization in a wide variety of high data rate and multimedia services, higher frequency bands need to be allocated and utilized for these services. New devices and components for high frequency and millimeter wave integrated front-end receivers are being developed, active and low cost phased array antennas are being designed, and advanced software issues in coding, modulation, switching, and networking are being researched and developed. In addition to these rather obvious advances that are needed to enable the next generation wireless technology, developing new and more computationally efficient propagation models is also essential. Development of reliable propagation models and the availability of the associated simulation software tools would be absolutely necessary for the successful implementation of the future terrestrial wireless systems and also for their integration with other technologies.
including the satellite, LMDS, and the wireline based services. Accurate propagation models will help in using the rather congested frequency spectrum more efficiently, in planning more effective radio networks, and in implementing cost effective solutions for a desirable and user specific communication coverage pattern.

PROPAGATION MODELS FOR URBAN ENVIRONMENT

For urban propagation, three distinct models can be used. These include propagation in macrocells, microcells, and indoor or picocells. In macrocells, the base station is often placed well above an average rooftop, while for microcells the base station is placed well below the average rooftop. In macrocells, the propagation path is dominated by the over the rooftop path, while for microcells reflections and diffraction from buildings and streets often dominate the propagation environment. For such environments, ray tracing-type simulation models are adequate and their use is justifiable. For picocells and indoor propagation, on the other hand, new challenges appear and improved propagation models and simulation tools are required to achieve reliable, accurate, and computationally efficient propagation predictions and to help overcome many of the indoor propagation impairments. Challenges facing the development of picocell simulation tools may include the following:

- Propagation predictions depend primarily on often unavailable building construction parameters such as wall thickness, materials, and indoor building structures.
- Exclusive use of ray tracing-based propagation models may be inadequate. Available ray tracing procedures often encounter a large number of reflections and multiple transmissions and hence become time consuming and computationally inefficient.
- Lack of knowledge of diffraction coefficients for many indoor structures may also compromise the accuracy of available ray tracing simulation methods.
- The ray tracing procedure and the geometrical theory of diffraction are high frequency techniques, and dimensions of some of the indoor structures may not necessarily satisfy the small dimensions compared to the wavelength criterion required by these methods.

It is often argued that results from deterministic electromagnetic-based calculation models are not expressed in terms of parameters that can be used in the simulation of wireless communications systems. Parameters such as delay spread, coverage, direction of arrival, and bit error rate (BER) are necessary for system simulations and need to be incorporated as part of the simulation code development.

Four different types of methods are often used in developing propagation models, and the above listed limitations are expected to impact them differently. For example, statistical models provide parameters suitable for system simulations but lack specificity and accuracy. EM-based deterministic models, on the other hand, provide accurate and site specific coverage and delay spread information but are also very computationally inefficient and time consuming. Empirical and measurement-based models are site specific, frequency specific, and hence lack generality. Researchers use a combination of these methods to help improve the accuracy, broaden the generality, and reduce the required computational time. But much more research and development are needed to fully develop accurate, computationally efficient, and experimentally verified propagation models that may be used for broadband and highly mobile communications systems. With the advances in the signal processing methods and the development of communications algorithms, the envisioned propagation models are expected to play a critical role in the accurate accounting for mobility and the dynamic variation in the characteristics of the propagation channels.

With this in mind, the panel members tried to identify and possibly discuss the on-going R&D activities in this area of channel characterization and propagation models as we continued to travel in Europe and Japan. Only at Philips, CSELT, and Ericsson in Europe, and Matsushita Research Institute Tokyo (MRIT), KDD, and YRP in Japan did the panel identify research activities that the host was interested in sharing and discussing. The following provides a summary of these activities and a comparative study of the level of
interest and the type of emphasis in each case. This summary will be presented according to the modeling and the characterization technique used in research activities at the visited sites.

Deterministic EM-Based Propagation Models

The WTEC panel identified strong research activities in this area at Philips and Ericsson. At Philips, new deterministic models for indoor propagation are being developed based on modal expansion techniques and using the Finite Difference Time Domain Method (FDTD). In both cases, both the EM field distributions and statistical parameters such as coverage and delay spread were being calculated (Dolmans 1997). Examples of the obtained results using a 2D FDTD code are shown in Fig. 4.1 for two different indoor propagation environments. Results from some of the statistical parameters calculations are shown in Fig. 4.2 where both the delay spread profile for propagating pulses of different widths and the coverage for single and diversity antennas were calculated. Results from these calculations are being experimentally evaluated using experimental set ups such as the one shown in Fig. 4.3. The important observation from this effort is related to the fact that efforts are being made to include calculations of statistical parameters of interest to system simulations and to verify the results experimentally. The use of 2D FDTD calculations emphasize the need for a more computationally efficient procedure to carry out 3D calculations often required in indoor simulations.

The research activities at Ericsson are closely tied with the European Cooperation in the Scientific and Technical Research (COST) in this area.

The COST 295 task force on “Wireless Flexible Personalized Communications” has a working group (Working Group 2) on propagation and antennas. This working group, chaired by Prof. E. Bonek from the Technical University of Vienna, has the following stated objectives:

- develop new EM-based deterministic models for UHF, microwave, and millimeter wave
- study and optimize models for short range communications
- conduct a comparative study of the effectiveness of empirical/statistical and electromagnetic deterministic models for different propagation environments and situations
- conduct measurements to validate accuracy and improve efficiency

As part of this activity, Mr. M. Steinbaur, also from the Technical University of Vienna, is leading an effort to provide characterization for wideband and time-varying directional channels and to ensure that models meet requirements posed by system and network simulations. A summary of the progress and discussion of activities of the COST 295 task force, working group 2, is available elsewhere (COST 295/260 Workshop 1999; Landstorfer 1999).

Fig. 4.1. Fluctuations of the electric field in the building that houses the faculty of Electrical Engineering. 2D FDTD code was used in these calculations which include the following: (a) all doors are open with no object present; (b) doors are closed with one object placed in one of the rooms. Green color denotes high electric field values; blue color represents low signal amplitudes.
Ray Tracing-Based Propagation Models

The ray tracing method represents the most commonly used approach in the calculation of propagation models for terrestrial and urban environments. Several software packages are available (Bertoni et al. 1994; Liang et al. 1998; Rappaport et al. 1992), and some research efforts are underway to help in the continued improvement of the accuracy and extension of generality and to increase computational efficiency. The conventional ray tracing method is based on a ray launching and bouncing procedure that can be very inefficient if no speed-up algorithm is employed. There have been several schemes to accelerate this procedure including the image method, the bounding box method, and the utilization of the visibility
approach (Landstorfer 1999; Liang et al. 1998; Catedra et al. 1998). Although these methods have their own advantages and specific domains of applications, more efficient methods are needed to cope with the complex and often computationally demanding indoor or indoor/outdoor situations while maintaining good accuracy of the propagation prediction results. Such research activities were found at CSELT in Italy and KDD Research and Development Laboratories in Japan. At CSELT results from several models were presented including site specific ray tracing predictions which were time consuming; ray-launching results, which were faster but lacked accuracy; and semi-deterministic methods, which were being used in small cell planning. For indoor propagation, however, empirical models based on experimental measurements were being used. Results from these calculations were presented in terms of field distributions in the propagating environment, delay spread distribution, and Doppler frequency distribution. An example of the presented results for a microcellular structure is shown in Fig. 4.4.

![Example Figure](image)

**Fig. 4.4.** Microcell structure (L.) and ray tracing results (R.) of delay profile in a parking lot (CSELT).

At KDD two tools were developed. These include the CSPLAN tool, which is used for cell site planning and coverage evaluation using low antenna height and 2D building shapes, and the BSPLA tool, which provides propagation predictions for mobile based station planning. For the BSPLA tool, path loss is evaluated based on geographic information of the propagation area. This effort at KDD points to other ongoing research activities in the area of channel characterization and propagation models development, including the use of geographic information and data from the Global Positioning System (GPS) to guide the development and enhance the accuracy and the computational efficiency of new propagation models for future wireless communications systems (Enge 1994; Kaplan 1996). This may provide significant advantages in systems that intend to incorporate dynamic variations in channel characteristics. For mobile multimedia wireless applications, incorporation of such capabilities may be crucial in enhancing the quality of service or making it even possible in the first place.

### Propagation Models At Millimeter Waves

Besides the stated objective by the COST 295 working group, the issue of developing propagation models at millimeter wave frequencies was not discussed in any of the visited European sites. Two groups in Japan, however, discussed R&D activities in this area. These include the MRIT and the Stratospheric Wireless Access Network group at the Yokosuka Research Park (YRP). At MRIT new propagation models are being developed at millimeter wave frequencies, and emphasis is placed on the accurate accounting of multi-path analysis. At YRP, on the other hand, propagation models are being developed to support the development of a stratospheric platform. This unmanned High Altitude Platform Station (HAPS) is expected to fly at an altitude of 22 km, and 15 platforms are expected to provide coverage for all of Japan. Frequencies in the range from 2-20 GHz will be used with the continued increase in attainable data rates. Figure 4.5 shows that optical links will be used for inter-platform communications and radio links will be used for subscriber
access. Propagation models that cover this entire frequency band are being developed, and research activities expected to improve the accuracy and enhance the computational efficiency will continue for some time.

**Empirical and Measurement-Based Propagation Models**

Clearly many of these models are presently available and are being used in a variety of wireless services. Limited aspects of these models were, however, discussed in the visited sites during this study. As mentioned earlier, the COST 295 task force is involved in a comparative study of the effectiveness of empirical and statistical vs. electromagnetic deterministic models in different situations. The CSELT group is also using this type of empirical model for indoor propagation studies and channel predictions. The limited interest in this area may be justified based on several drawbacks including the following:

- the large number of time-consuming measurements required
- the site specific nature of the data and their limited broad utilization in various propagation environments
- lack of accuracy

The main reason for the attractiveness of such approaches is computation speed. Furthermore, results from these measurements and empirical curve fitting efforts are sometimes used to complement ray tracing-type calculations and provide improved accuracy in areas where it is difficult or time consuming to incorporate numerical calculations of diffraction coefficients.

**Technology Assessment**

In addition to the information learned and collected during site visits, the WTEC panel tried to further assess research activities in this area by searching the INSPEC database for some of the key words related to this topic. Selected key words include propagation models, channel characterization, and indoor-outdoor propagation models. The results from the database search are summarized in tables 4.1a, 4.1b, and 4.1c in terms of the number of papers published or presented on this subject. From these results it may be noted that research on the development of propagation models is strongest in Europe, followed by the United States, while the research activities in the area of indoor-outdoor propagation models are rather limited (only 20
papers cited during the period from 1995-99) with major participation by the European community. These results also emphasize the need for new R&D for modeling micro- and pico-cells.

Table 4.1a
Propagation Models (1998-1999)*

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<tr>
<td>Others</td>
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*Results of the database search using INSPEC. Total number of papers, 100.

Table 4.1b
Channel Characterization (1997-1999)*

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*total number of papers 42

Table 4.1c
Indoor-Outdoor Propagation (1995-1999)*

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<tr>
<td>Others</td>
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<td>25%</td>
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*total number of papers 20

For the overall comparative study among Europe, Japan, and United States in the area of channel characterization and modeling, Table 4.2 was prepared to provide a qualitative comparison. From Table 4.2 it may be noted that while the majority of the available models are based on the computationally efficient statistical and empirical models, there is some growing interest in using EM-based deterministic models particularly in the United States followed by Europe. Efforts to integrate statistical parameters in the models are being mostly emphasized in Europe followed by the United States. It is expected that this trend will continue to grow because of the continued demand for improved accuracy and reliability in system designs and network planning. Table 4.2 also shows some growing interest in modeling new wireless communications systems in the millimeter wave frequency range in both Japan and the United States, while much of the European activity is presently focused on addressing the present industrial needs at lower RF frequencies.
Table 4.2
Research Activities in the Channel Characterization and Propagation Models in Europe, Japan and the United States

<table>
<thead>
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<th>Research Activities</th>
<th>Europe</th>
<th>Japan</th>
<th>USA</th>
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<tbody>
<tr>
<td>Statistical/empirical</td>
<td>***</td>
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<tr>
<td>EM based deterministic</td>
<td>**</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>Integrative models (Statistical parameters based on deterministic models)</td>
<td>**</td>
<td>-</td>
<td>*</td>
</tr>
<tr>
<td>Microwave and millimeter wave</td>
<td>*</td>
<td>**</td>
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</table>

*Qualitative results of a comparative study illustrating the level of activities and the focus of research in Europe, Japan, and the United States in the area of channel characterization and propagation models.

KEY RESEARCH ISSUES

From the preceding discussion and keeping in mind the stated vision for next generation wireless technology of fully integrated, reliable, multimedia services with full mobility and minimum latency, the following key research activities in the channel characterization and propagation model development may be suggested:

- new models for microwave and millimeter wave wireless systems
- models for broadband wireless systems including polarization diversity and mobility effects
- computationally efficient deterministic/quasi-deterministic models that maintain good accuracy and generality of application
- integrated models that provide statistical parameters relevant to system and network simulations
- experimental measurements on scaled models or realistic channels to validate simulation results and provide guidance for identifying the most important contributions to propagation impairments and interference effects

While emphasis in this chapter was placed on channel characterization and propagation models, it is important to point out that multidisciplinary efforts that incorporate knowledge of the channel characteristics to develop and implement novel signal processing methods, communication algorithms, and networking protocols represent a most effective strategy in advancing wireless communications systems. Every effort should be made to participate in these integrative and multidisciplinary approaches rather than focusing on isolated and individual efforts in channel characterization and modeling.

In addition to the need for integrative efforts, there is no question that research efforts must focus on the development of a physics-based channel model that effectively takes advantage of the identified dominant effects in a given propagation environment and frequency band while maintaining good accuracy. A broad range of applicability and acceptable computational efficiency will provide next generation wireless communications systems with a significant tool and a most valuable enabling technology. Understanding the physical nature of the wireless communication channel and incorporating this developed fundamental understanding across the communications layers is crucial for realizing the much anticipated benefits from the wireless information technology and networks.

REFERENCES


Landstorfer, F. 1999. “Wave propagation models for the panning of mobile communication networks.” Plenary presentation read at European Microwave Conference, 4-8 October, Munich, Germany.


