A Review of Propagation Models for Mobile Communication System

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Abstract--**To estimate the signal parameters accurately for mobile systems, it is necessary to estimate a system's propagation characteristics through a medium. Propagation analysis provides a good initial estimate of the signal characteristics. The ability to accurately predict radio-propagation behavior for wireless personal communication systems, such as cellular mobile radio, is becoming crucial to system design. Since site measurements are costly, propagation models have been developed as a suitable, low-cost, and convenient alternative. Channel modeling is required to predict path loss and to characterize the impulse response of the propagating channel. This paper takes a review of the information available on the various propagation models for both indoor and outdoor environments. .The existing models can be classified into two major classes: statistical models and site-specific models. The main characteristics of the radio channel are path loss that is to be discussed. The advantages and disadvantages of some of these methods are summarized.**

Keywords--**Land mobile radio cellular systems, mobile radio propagation factors, multi-path channels, Ray tracing and Ray launching**

I. INTRODUCTION

AS the explosive growth of mobile communications continues, it is very valuable to have the capability of determining optimum base-station locations, obtaining suitable data rates, and estimating their coverage, without conducting a series of propagation measurements, which are very expensive and time consuming. It is therefore important to develop effective propagation models for mobile communications, in order to provide design guidelines for mobile systems.

II. PROPAGATION IN OUTDOOR AND INDOOR ENVIRONMENTS

As increase in the capacity of mobile communications, the size of a cell is becoming smaller and smaller: from macro-[1]cell to micro-cell, and then to pico-cell. The service environments include both outdoor and indoor areas.

When propagation is considered in an outdoor environment, one is primarily interested in three types of areas: urban, suburban, and rural areas. The terrain profile of a particular area also needs to be taken into account. The terrain profile may vary from a simple, curved Earth to a highly mountainous region. The presence of trees, buildings, moving cars, and other obstacles must also be considered. The direct path, reflections from the ground and buildings, and diffraction from the comers and roofs of buildings are the main contributions to the total field generated at a receiver, due to radio-wave propagation.

With the advent of personal communication systems (PCS), there is also a great deal of interest in characterizing radio propagation inside buildings. The indoor radio channel differs from the traditional outdoor mobile radio channel in two aspects: the distance covered is much smaller, and the variability of the environment is much greater for a much smaller range of transmitter and receiver separation distances [01]. Propagation into and inside buildings has, to some extent, a more complex multi-path structure than an outdoor propagation environment. This is mainly because of the nature of the structures used for the buildings, the layout of rooms and, most importantly, the type of construction materials used. [02].

There are two main models for characterizing path loss: empirical (or statistical) models, and site-specific [or deterministic) models. Empirical models are based **on** the statistical characterization of the received signal. They are easier to implement, require less computational effort, and are less sensitive to the environment's geometry. site-specific models have a certain physical basis, and require a vast amount of data regarding geometry, terrain profile, locations of building and of furniture in buildings, and ***so*** on. These deterministic models require more computations, and are more accurate.

III. EMPIRICAL OR STATISTICAL MODELS FOR PATH LOSS

A. OUTDOOR CASE :

There are a number of empirical or statistical models suitable for both macro-cell and micro-cell scenarios for the outdoor environment. Some of these are described below.

1) Okumura Model:

This is one of the most widely used models for propagation in urban areas [03]. The model can he expressed as

$$L(dB) = L_f + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \qquad (1)$$

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where , L is the median value of the propagation path loss, L_f is the free-space propagation loss, ***A,,*** is the median attenuation in the medium relative to free space at frequency ; and ***d*** corresponds to the distance between the base and the mobile unit. $G(h_{te})$ and $G(h_{re})$ are the gain factors for the base-station antenna and the mobile antenna, respectively. h_{te}, and h_{re} are the effective heights of the base-station and the mobile antennas (in meters), respectively. G_{AREA} is the gain generated by the environment in which the system is operating. Both ***A,,*** (/,d) and G_{AREA} can be found from empirical curves. Okumura et al.'s model is considered to he among the simplest and best in terms of accuracy in predicting path loss for early cellular systems. It is very practical, and has become a standard for system planning in Japan. The major disadvantage of this model is its slow response to rapid changes in terrain profile.

2) *Hata model:*

The Hata model is an empirical formulation [04] of the graphical path-loss data provided by Okumura's model. The formula for the median path loss in urban areas is given by

$$L(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_{te}) - a(h_{re}) + (44.9 - 6.55\log(h_{re}))\log(d) \quad (2)$$

Where f_c is the frequency (in MHz), which varies from 150 MHz to 1500MHz. h_{te}, and h_{re} are the effective heights of the base station and the mobile antennas (in meters), respectively. d is the distance from the base station to the mobile antenna, $a(h_{re})$ is the correction factor for the effective antenna height of the mobile unit, which is a function of the size of the area of coverage. For small- to medium-sized cities, the mobile-antenna correction factor

is given by

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8)dB \quad (3)$$

For a large city, it is given by

$$a(h_{re}) = 8.29(\log 1.54 h_{re})^2 - 1.1 dB$$

for $f_c \leq 300$ MHz (4)

$$a(h_{re}) = 3.2(\log 11.75 h_{re})^2 - 4.79 dB$$

for $f_c \geq 300$ MHz (5)

To obtain the path loss in a suburban area, the standard Hata formula is modified as follows:

$$L(dB) = L(urban) - 2\left[\log\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \quad (6)$$

The path loss in open area is expressed through

$$L(dB) = L(urban) - 4.78[\log(f_c)]^2 - 18.33\log f_c - 40.98. \quad (7)$$

This model is quite suitable for large-cell mobile systems, but not for personal communications systems that cover a circular area of approximately 1km in radius.

3) *Cost-231-Walfisch-Lkegami Model:*

This model utilizes the theoretical Walfisch-Bertoni model [05], and is composed of three terms:

$$L_b = L_0 + L_{rts} + L_{msd} \quad \text{for} \quad L_{rts} + L_{msd} \rangle 0 \quad (8)$$

$$L_b = L_0 \quad \text{for} \quad L_{rts} + L_{msd} \leq 0 \quad (9)$$

where L_0 represents the free-space loss. L_{rts} is the "roof-top-to street diffraction and scattering loss."

L_{msd} is the "multi-screen diffraction loss." The free-space loss is given by

$$L_0 = 32.4 + 20\log d + 20\log f \quad (10)$$

Where, d is the radio-path length (in km), f, is the radio frequency (in MHz), and

$$L_{rts} = -16.9 - 10\log w + 10\log f + 20\log \Delta h_{mobile} + L_{ori} \quad (11)$$

Here, *w is* the street width (in m), and

$$\Delta h_{mobile} = h_{Roof} - h_{mobile} \quad (12)$$

is the difference between the height of the building on which the base-station antenna is located, h_{Roof}, and the height of the mobile antenna, h_{mobile}. L_{ori} is depending on angle of incident relative to direction of street.

L_{msd} is given by,

$$L_{msd} = L_{bsh} + K_a + K_d + K_f \log f - 9\log b \quad (13)$$

where *b* is the distance between the buildings along the signal path. K_a and L_{bsh} represent the increase of path loss due to a reduced base-station antenna height.

This model is being considered for use by the International Telecommunication Union Radio-communication Sector (ITU-R) in the International Mobile Telecommunications - 2000 (IMT-2000) standards activities

4) *Dual- Slope Model:*

This model is based on a two-ray model [06,07], which is used commonly when the transmitting antenna is several wavelengths or more above the horizontal ground plane. It is suitable for the line-of-sight **(LOS)** propagation regions. The propagation loss, L(d), in this case is described by a dual-slope model. This can be represented as function of d, the distance between the base station and the receiver. It is given by [07] [26]

$$L(d) = L_b + 10\log d + P_1 \quad 1 < d < d_{brk} \quad (14)$$

$$L(d) = L_b + 10(n_1 - n_2)\log d_{brk} + 10 n_2 \log d + P_1 \quad d \geq d_{brk} \quad (15)$$

where P, = PL(do), the path loss in dB at the reference point, do. dbrk represents the breakpoint or the turning-point distance. The 'point" where this transition occurs is often called the Fresnel breakpoint. Lb is a basic transmission-loss parameter that depends on frequency and the antenna heights, and n1 and n2 represent the slopes of the best-fit line before and after the breakpoint. If the transmitter and receiver antenna heights are known, along more variability in the path loss and the exponent for the region beyond the Fresnel breakpoint, with values of n2 ranging from two to seven.

B. OTHER MODELS:

Other models, including the use of wideband measurements for different situations, have been discussed in recent times [08,12]. These models have been developed from measurements, and use different parameters for different situations.

IV. SITE-SPECIFIC MODELS FOR PATH LOSS

Site-specific propagation models, also called deterministic models, are based on the theory of electromagnetic-wave propagation. Unlike statistical models, site-specific propagation models do not rely on extensive measurements, but on knowledge of greater detail of the environment, and they provide accurate predictions of the signal propagation.

In theory, the propagation characteristics of electromagnetic waves could he computed exactly by solving Maxwell's equations. Unfortunately, this approach requires very complex mathematical operations and requires considerable computing power. In reference [08], this method has been applied to simplified environments.

A. Ray-Tracing Technique

Ray tracing is a technique based on Geometrical Optics (GO) that can easily he applied as an approximate method for estimating the levels of high-frequency electromagnetic fields. GO assumes that energy can be considered to be radiated through infinitesimally small tubes, often called rays. These rays are normal to the surface of equal signal power. They lie along the direction of propagation and travel in straight lines, provided that the relative refractive index of the medium is constant. Therefore, signal propagation can be modeled via ray propagation. By using the concept of ray tracing, rays can be launched from a transmitter location, and the interaction of the rays can be described using the well-known theory of refraction and reflection and interactions with the neighboring environment. In GO, only direct, reflected, and refracted rays are considered. Consequently, abrupt transition areas may occur, corresponding to the boundaries of the regions where these rays exist. The Geometrical Theory of Diffraction **(GTD)** and its uniform extension, the Uniform GTD (UTD) [09]**,** complement the GO theory by introducing a new type of rays, known as the diffracted rays.

The ray-tracing method is widely used in propagation-model and system design [10, 11, 12]. It is most accurate when the point of observation is many wavelengths away from the nearest scatterer. All scatterers are assumed to he large when compared to a wavelength. Two types of ray-tracing methods ~ the image method [13]. and the brute-force ray-tracing method - are generally used. These are now explained.

B. Image Method

This method generates the images of a source at all planes. These images serve as secondary sources for the subsequent points of reflections. If there are N reflecting planes, then there are N first order images of a source, $N(N-1)$ two reflection images, $N(N-1)(N-1)$ three-reflection images and so on [14]. To determine whether an image of the source is visible at the destination is to trace the intersection of the reflected ray at all the necessary planes of interest. Thus, the energy reaches the destination through multiple reflections and contributes to the received power. Once a ray bas been traced through all its reflections to the source, the attenuations associated with all the reflection terms are calculated.

The image method is efficient, but it can only handle simple environments. Many environments with which we are concerned in our daily life are complicated, and the conventional image method is not adequate

1) Brute-Force Ray-Tracing Method

This method considers a bundle of transmitted rays that may or may not reach the receiver. The number of rays considered and the distance from the transmitter to the receiver location determines the available spatial resolution and, hence, the accuracy of the model. This method requires more computing power than the image method.

The procedure of ray tracing in three dimensions is similar to a two-dimensional model, but more computational time is needed. Some sectors of the walls in corridors can be made of different materials, for example, wood, metal, concrete, or even glass, which may have different reflectivity's for the incident wave. Neglecting the differences among the reflectivities of the various materials will degrade the prediction accuracy of the propagation model.

The key to a propagation model based on ray-tracing is to find a computationally fast way to determine the dominant ray paths so as to provide accurate path-loss predictions To improve the efficiency of ray-tracing models, many researchers have developed a large number of methods [15]. In [15], a hybrid technique was presented, where the object database was held in two dimensions, but a ray-tracing engine operated in three dimensions. The three-dimensional rays were produced by combining the results of two two-dimensional ray tracers, one on a horizontal plane and the other on a vertical plane

C. FDTD Models

Based on Geometrical Optics *(GO)* and usually supplemented by UTD, a ray-tracing algorithm provides a relatively simple solution for radio propagation. However, it is well known that GO provides good results for electrically large objects, and UTD is rigorous only for perfectly conducting wedges. For complex lossy structures with finite dimensions, ray-tracing fails to correctly predict the scattered fields. In a complicated communication environment, transmitting and receiving antennas are often inevitably installed close to structures with complex material properties for which no asymptotic solutions are available. Such problems can be solved by numerical solution of Maxwell's equations. In particular, the Finite-Difference Time-Domain (FDTD) method is an alternative.

The advantages of the FDTD method are its accuracy, and that it simultaneously provides a complete solution for all the points in the map, which can give signal-coverage information throughout a given area.

In a simple outdoor environment, a two-dimensional FDTD is generally applied [16]. A simple approach for introducing the correct spherical-wave spreading has been developed. A comparison with FDTD predictions could be used to evaluate and refine the GTD-based methods.

D. Moment-Method Models

Ray-tracing models can be used with sufficient precision to predict radio coverage for large buildings having a large number of walls between the transmitter and the receiver, while the Method of Moments (MOM) model is better when higher precision is required and when the size of the buildings is smaller. A combination

of these two models is also possible, using the advantages of each of them. For cases where a lot of small but dominant obstacles are present, or where there are paths that cannot be taken into account by a ray-tracing model, the MOM model can be used [17].

E. Artificial Neural-Network Models

The main problem with the statistical models is usually the accuracy, while the site-specific models lack computational efficiency. The use of artificial neural networks (ANN's) has shown very good performance in solving problems with mild non- linearity on a set of noisy data. This case corresponds to ***a*** problem of field-level prediction, as the data obtained from measurements is always noisy. Another key feature of the neural network is the intrinsic parallelism, allowing for fast evaluation of the solutions. [18]

V. CONCLUSION

Propagation models are needed not only for installation guidelines, but they also play a key part in any analysis or design that strives to mitigate interference. In this paper, we have focused some of the typical propagation models that provide good estimates for both large-scale and small-scale fading channels.

Despite the enormous efforts to date, much work remains in understanding and predicting the characteristics of mobile communications channels. In addition, an efficient ray-tracing method has been presented for tracing rays in an indoor propagation system. An FDTD method has been described to analyze wave propagation through the walls in a building.

VI. ACKNOWLEDGEMENT

The author would like to thanks Mr. B. Godbole for his valuable help with preparing this paper.

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