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Wireless Channel Modeling Methods: Classification, Comparison and Application

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Abstract—**This paper presents classification of the related methods used in wireless channel modeling, including mathematical modeling, stochastic modeling, Ray-tracing, Ray-launching, FDTD. The comparison between the empirical models and the deterministic models helps to distinguish the application situation of each channel model. Therefore, the study will promote the wireless channel models development, and optimize the channel characteristics.**

Index Terms—**Empirical Models, Deterministic Models, Ray-tracing, Ray-launching, FDTD**

I. INTRODUCTION

Wireless channel is the transmission medium for mobile communication, all the information transmitted in this Channel. Channel performance directly determines the quality of the communication. Therefore, in order to get high-quality and high-capacity transmission of the useful information by using the more limited spectrum resources, we must have very clear understanding of the channel.

When the people get the sufficient understanding about the wireless propagation environment and the characteristics of propagation, Wireless channel model is known as an abstract description. Mobile channel has the worst stability compared to the other channels, because radio transmission in the mobile channel will have a large random fluctuation in time domain and space. It is difficult to control and measure, and the measurements will cost so much. Existing communication models is classified as the following: In Tokyo, Okumura with other researchers proposed the Okumura Model [1]. COST-231 Hata Model [2] is proposed by EURO-COST. Its frequency is extended to 2GHz. In 1982, W. C. Y. Lee proposed the Lee Model [3][4], which is widely used in the macro cell and the micro cell. Manhattan Model [5] is a mixed indoor to outdoor propagation model. Its attenuation is caused from outdoor to indoor.

All about these models above have their application scope, advantages and disadvantages. The main work of this paper is to summarize and compare the existing channel modeling methods. And it mainly focuses on the comparison between the empirical modeling methods and the deterministic modeling methods. The application of the channel modeling methods is given by classifying the wireless channel models. Furthermore, it can solve the issue in the wireless channel modeling more easily.

This paper is organized as follow: the second part mainly introduce the category of the channel modeling methods. The third and the forth part of the paper give the two channel modeling methods, the empirical modeling methods and the deterministic modeling methods, respectively. The fifth part gives the channel models classification based on modeling methods. The last part is the conclusion.

II. CHANNEL MODELS METHODS CATEGORY

In the following part, how to convert the mathematical description to the general form of the simulation model are discussed.

Channel Modeling mainly has three applications:

- As computer simulations rather than field testing are used for optimization of the base station (BS) location and other network design parameters, we need to provide a similar database to the wireless networks designers. The designers can make full use of the channel model information extracted from the database, which contains the information of the channel forms and geographic in specific location. This model must be stable enough to avoid the small errors that may exist in the geographic database.
- In the wireless system designing, testing and stereotypes, we need to know the properties that will affect the system performance, which are extracted from a simple channel model. The channel properties are generally gotten by simplifying the statistical characteristics of the channel model, which is described by the form of the impulse response parameters. This method need less number of parameters, and is independent of specific location. At the same time, the system designers need to verify the model by field testing.
- Summarized and analyzed the existing channel model and its characteristics. Thus, the applied limitations of the channel parameters are summarized. It can also refine the broader parameters of the channel. These parameters can be used in the development of next

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generation broadband wireless mobile communication network.

Therefore, the channel modeling methods classification needs to be investigated to direct the wireless communication system design. The two main classes of channel modeling methods are as follows:

A. Empirical modeling method:

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The methods using in the empirical model are mainly divided into two parts:

1) Stored channel impulse response:

Channel sounder deal the impulse response with measurement, digital, and storage. The advantage of this method is that the impulse response can be closer to reality. Moreover, because the data can be recycled, and even can be applied to the simulation in different systems and the method is renewable.

Disadvantage of this approach is that the data can only characterize a region, lack of typicality. Access and storage of these data requires a lot of work to do.

2) Stochastic channel modeling method:

By studying the probability density function, establishment of the channel impulse response derives the channel model. This modeling method is not to correctly predict the channel impulse response of a specific environment, rather than predicting a large range of the probability density function. The simplest example here is the Rayleigh fading model. Abandoning the field strength for each position, but rather try to determine the probability density function of a wide range of the field strength information, in order to establish random broadband model. In general, the stochastic model mainly applied in the system design and comparison, while specific regional model is more suitable for network planning and system development. Deterministic and stochastic methods can be combined to enhance the efficiency of the model. For example, through the deterministic model, we can get large-scale average power, while seeking changes in the average of the region is described with a stochastic channel model.

B. Deterministic modeling method:

We use the information of form and geography in the database to determine the Maxwell's equation exact solution or the approximate solution. The basic idea is the same as the impulse response storage: to determine the impulse response that has a sure location. Thus, they belong to different region-specific model. This approach has the advantage that computer simulation is much easier than measurement in actual practice, and some parameter estimation methods, such as ray-tracing, allow the impact of different propagation mechanisms to be independent of each other. Compared with the storage channel impulse response method, its disadvantage is the large amount of calculation, the results of the approximate method of calculation and inaccuracy of the original data is not very accurate.

III. Empirical Modeling Methods

According to different scenarios, empirical model is divided into two parts: outdoor empirical model and indoor empirical model.

A. Outdoor empirical modeling method

Outdoor empirical model is generated based on a large number of measurements. And the model is different from the macro-cell outdoor propagation model in the following aspects:

- This model is applicable to small range (only for the base station in the nearby area). This is a common feature of micro-cellular model;
- The receiving antennas are near the transmitting antennas. Only the outdoor propagations of the region near the transmitting antennas is considered;
- The diffraction of the building is constituted mainly by the roof diffraction.

Empirical model is very similar to the traditional linear model. When the antenna height is low (5m), the linear model is closed to the experimental data. However, with the antenna height increasing, the accuracy of empirical model is much higher than measured model. The study showed that in the small area, empirical model is also better than the Okumura model.

The disadvantage is: there is a greater transmission loss at the street corner; even if the corner is a few dozen meters from the base station. The loss is likely to be 20 ~ 25dB

B. Indoor empirical modeling method

1) Mathematical modeling:

Indoor wireless channel is modeled through mathematical modeling approach. The indoor radio propagation channel is complex, stochastic and time-varying at each point of three-dimensional space, which is regarded as a time-varying linear filter.

The channel impulse response is defined as:

$$h(t,\tau)=\sum_{k=1}^{N(t)} a_k(t)\delta[t-\tau_k(t)]e^{j\theta_k(t)} \tag{1}$$

where $a_k(t)$ is the time-varying amplitude, $\tau_k(t)$ is the arrival time and $\theta_k(t)$is the phase. Any transmitted signal convolving with the channel impulse response and adding the channel noise, we can obtain the channel response. This method refers to wireless channel impulse response method. This mathematical model is also a broadband model.

Discrete-time impulse response model describes the multipath propagation channel characteristics. In this model, we divide the timeline into many small time periods, called bins. Each bin is corresponding to zero or one propagated path.

Because the two paths cannot be distinguished if they reached at the same time, we should determine the size of a reasonable time period by measurement. Thus, we could use "1" and "0" to indicate that the propagated path in that time period exists or not, respectively. Simultaneously, each "1" corresponds to different amplitude and phase information.

Unmodulated carrier is transmitted in multipath environment. The receiver will receive continuous wave envelope with too rapid fluctuations due to various paths superimpose. In order to derive corresponding narrow-band model from the wide band model, we define the transmit signal as 1, not considering the impact of the noise factors. We could get the continuous-wave envelope and the results of the phase correlation. As sample the channel impulse response at a large enough sampling frequency, we can get the fading result of narrow-band continuous-wave.

2) Statistical modeling:

For wireless communication channel, the statistical model mainly considers the arrival situation of each main wave which consists of a series of the main points in the space. The main wave, including LOS (line of sight or straight line) situation and the rays reflected or scattered by the main object, can be represented by the pulse sequence of the amplitude, time and space in three-dimensional coordinates. The signal transmits from the base station through one or more main wave to the mobile receivers. The main wave is formed by the LOS wave and several reflection or scattering lines which are from the ceilings, walls, floors and others of buildings. LOS wave may be disturbed by objects to some extent, which can be no longer detected by the receiver. The main wave is scattered by building structures and furniture near the receiver. The delays that the main wave reaches are very close to each other. Every path has almost the same attenuation, while has different phases as the path length is different. Paths mix in accordance with the relative arrival time, amplitude and phase. We could receive the random envelope at the receiving end. In the measurement, we can record the number of distinguished paths. At specific space point, the number of the path depends on the shape and structure of the building and the measuring resolution.

IV. Deterministic Modeling Methods

From point of view of the electromagnetic wave theory, the radio transmission channel can generally be classified as deterministic channel model, so the deterministic model can also be called the fixed-point propagation model. There are mainly two methods used for modeling: ray-launching [7] or ray-tracing [8] technologies and FDTD [9] (finite-difference time-domain) method for the Maxwell equations solution.

A. Ray-launching or Ray-tracing Technology

The most common optical model is the ray-launching or ray-tracing technology. The advantages of this model are very accurate, and it can be used in a fixed location, also can predict broadband parameters. Its drawback is relatively slow in operation so that preprocess and simplification must be applied. Meanwhile, some models cannot correctly include diffraction. Moreover this model requires import data precisely, including the location geometry of obstacles and the electromagnetic parameters of all the material. The deterministic ray modeling approach is generally put the transmitter and receiver as a reference point in the three-dimensional coordinate system. Generally the indoor walls, ceilings and floors are defined as a plane with dielectric constant and thickness, whose surfaces are processed as plane sections. The simulation path is that rays emitted from the transmitter through walls, ceilings, floors, tables and other objects, reflected and reached the receiver through these objects.

1) Ray-tracing

The ray-tracing mirror image method using the principles of optics to simulate the propagation of electromagnetic waves is an effective technology of ray reflection calculation in the modeling. When the rays that are emitted from scattering objects near the observed point have many wavelengths, the sizes of all the scattering objects are more large and smooth than the wavelength. That is to say, when the surface features size is much smaller than a wavelength, ray-tracing method is more accurate. Suppose each plane in the room is a mirror, whose features are flat, thin and with silver. When the rays reach the mirror, the mirror may absorb a part of power, but the total power is not change. Thus, rays have the properties of initial power, direction and transmitted distance. Put the radio resource as a coherent, ray phase can be calculated before the superposition of the receiver. This method begins with transmitters as the forward ray-tracing method, can also start from the receiver, then track back to the transmitter, which is called the reverse ray-tracing method. Followed mirrored theory of the ray-tracing, as the geographical terrain is more complex, the number of the image is increased significantly.

2) Ray-launching

Ray-launching technique can also be referred to as SBR (Shooting and Bouncing Rays) method, which is widely used in solving radar cross-section and the scattering problem. Ray-launching method is that transmitter launch thousands of test rays. The true path is determined by looking for the rays closed to the receiver. In the early literatures, this technology and mirrored methods are both classified as ray-tracing method. But now, many literatures can distinguish these two methods. Ray-tracing method specifically refers to the mirrored method.

Ray-launching method is also put the location of the transmitter and receiver as discrete points in three-dimensional coordinates. Furthermore we need to consider all the rays' angle of the possible transmitter and receiver, in order to determine the entire possible transmission path from the transmitter and to the receiver. This approach must prevent counting a single ray path twice.

However, the two methods above cannot calculate the exact path. Although many problems can be solved by increasing the number of rays from the transmitter, the computational complexity is increased overall. When used the detect range to test the receiving path, the issue, which the single path is two calculated twice, is not easy to resolve. Applying additional filters to solve the problem above. It can eliminate the error path, as the repeat rays have the same wavelength and angle of arrival.

TABLE I. CLASSIFICATION OF THE CHANNEL MODELS

Outdoor Model	***Macro-Cell***	***Empirical Model***	Okumura Model
			Okumura-Hata Model
			COST-231 Hata Model
			LEE Macro-cell Model
			McGeehan & Griffiths Model
			Sakagami-Kuboi Model
			Ibrahim& parsons Model
		Semi-empirical Models or Semi-deterministic Models	Ikegami Model
			Bertoni-Xia Model
			Walfisch-Bertoni Model[11]
			COST 231- Walfish-Ikegami Model
	Micro-Cell		Two-lane model
			Multipath model
			Quasi-three-dimensional UTD model [12]
			LEE Micro-cell Model
			Broadband PCS Micro-cell Model
Indoor Empirical Model			Log Distance Path Loss Model
			SIRCIM
			Ericsson Multiple Breakpoints Model
			Keenan-Motley Model
			Multi-wall Model
			Attenuation factor Model
			Multipath impulse response of the statistical Model
Indoor-Outdoor Model			Mixed Indoor-Outdoor Propagation Model (Manhattan Model)

B. *Finite-Difference Time-Domain method*

The second method is FDTD method. It is a method of solving Maxwell's equations, which can accurately calculate the spread parameter values of a spatial point. By direct solving the Maxwell equations in the time domain, FDTD method fully explain the effects of reflection, diffraction and radiation. This method is suitable for studying the wave interaction in the medium. Its advantage is very accurate. Simultaneously, it can provide complete information of all points in the map. And it also can give signal coverage information of the whole region. It can be used as the standard to check and verify the other modeling techniques. As a mathematical analysis method, its drawback is the requirement of the plenty of storage space and huge computation, despite FDTD is still a relatively mature calculation.

Considering the ray-tracing or ray-launching techniques and FDTD techniques, they have their own advantages and disadvantages. So some researches want to combine these two technologies for wireless communication channel modeling [10]. Generally, we use the ray-tracing or ray-launching techniques to analyze the spacious area, while use the FDTD technique to study the location near the complex discrete area where the ray technology cannot be an accurate analysis. Taking into account the practicality of computing resources, FDTD only applied to a small part of the entire modeling environment.

V. CHANNEL MODELS CLASSIFICATION BASED ON MODELING METHODS

Through the analysis and comparisons of the wireless channel modeling methods above, we get a basis for the wireless channel model classification. The classification of the channel models are shown in TABLE I.

From the table above, the models could divide into three parts: outdoor, indoor and the mixed indoor to outdoor models. Outdoor models can be classified into macro-cell models and micro-cell models. And the macro-cell models can divide into empirical models and semi-empirical models or semi-deterministic models.

We can obtain the parameters from the classification of the wireless channel models. Then, make full uses on the development of the wireless communication.

VI. CONCLUSIONS

In this paper, the wireless propagated channel modeling method is classified as two categories: empirical modeling method and deterministic modeling method. And it also gives a comparison of their advantages and disadvantages. Then, it classifies the channel models according to these two kinds of modeling methods respectively.

Through this research, we can make better use of wireless channel modeling technology and methods to promote the rapid development of future wireless communications.

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