PREDICTION OF AVERAGE POWER DISTRIBUTION IN INDOOR WIRELESS COMMUNICATIONS BY USING RAY-TRACING TECHNIQUE

TÍNH TOÁN PHÂN BỐ CÔNG SUẤT THU
TRONG MÔI TRƯỜNG INDOOR BẰNG PHƯƠNG PHÁP RAY-TRACING

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ABSTRACT

The design of indoor wireless communication networks requires the prediction of average power distribution inside a building. Radio propagation inside a building is complex because each building wall can act both as an obstruction attenuating a propagation path, and as a mirror providing an additional path. The measurement techniques are normally high costs and time consuming. The prediction techniques based on the numerical calculation of electromagnetic field overcome the disadvantages of measurement techniques while providing high accuracy and being suitable for practical applications of cell planning and cell re-planning issues. The ray-tracing technique, which speeds up the computation while maintaining the reasonable accuracy, is an appropriate selection. In this paper, we develop a software program for predicting distribution of average power in indoor wireless communications based on ray-tracing technique. The efficiency of the proposed software program is shown in numerical results and is verified by measurement results.

TÓM TẮT

Thiết kế mạng không dây trong nhà đòi hỏi chúng ta cần phải dự đoán được công suất trung bình phân bố trong tòa nhà. Việc truyền sóng vô tuyến trong nhà rất phức tạp bởi vì mỗi bức tường của tòa nhà có thể là vật cản trở đường truyền sóng, mà cũng có thể là 'tấm gương' tạo ra đường truyền sóng khác. Những kỹ thuật đo đạc thực nghiệm thường rất tốn kém vì phải dùng máy đo lường cường độ trường và tốn nhiều thời gian đo đạc. Trong khi đó, những kỹ thuật dự đoán dựa trên việc tính toán số của trường điện từ khắc phục được những nhược điểm trên của kỹ thuật đo đạc đồng thời cho kết quả gần khớp với thực tế, phù hợp cho những ứng dụng thực tiễn trong quy hoạch và tái quy hoạch mạng. Kỹ thuật ray-tracing là một trong những kỹ thuật dự đoán nêu trên, không những tăng tốc việc tính toán mà còn duy trì được độ chính xác. Bài viết này trình bày phần mềm dự đoán sự phân bố công suất trung bình được xây dựng dựa trên kỹ thuật ray-tracing. Tính hiệu quả của chương trình được thể hiện qua kết quả mô phỏng và kết quả đo đạc thực tế.

I. INTRODUCTION

The commercial success of cellular communications, since its initial implementation in the early 1980s, had led to an intense interest among wireless engineers in understanding, and predicting radio propagation characteristics in various urban and suburban areas, and even within buildings. As the explosive growth of the mobile communications, it is very valuable to have the capability of determining optimum base-station locations, 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.

The paper is organized as follows. Section 2 states the importance of propagation prediction in designs and planning/replanning of wireless communication systems. Section 3 shows some propagation prediction models which can be used for predicting average power distribution. In section 4, the prediction of indoor radio power using RT (Ray-tracing) software is compared to data collected from measurements.

II. IMPORTANCE OF PROPAGATION PREDICTION

Before implementing designs and confirming planning of wireless communication systems, accurate propagation characteristics of the environment should be known. The path loss information is vital for the determination of coverage of a base-station (BS) placement and in optimizing it. Without propagation predictions, parameter estimations can only be obtained by field measurements which are time consuming and expensive. The following sections provide a brief description of deterministic and statistical models.

III. PROPAGATION PREDICTION MODELS

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

3.1 Statistical Models for Path Loss

1. Okumura Model and Hata Model

The Okumura model [2] is an empirical model based on extensive measurements made in Japan. This model is basically developed for macro-cells. It takes into account some of the propagation parameters such as the type of environment and the terrain irregularity. The Hata model [2] is a formula based Okumura model (graphics-based) and can be used more effectively.

2. COST 231-Walfisch-Ikegami Model

This model is being considered for use by the International Telecommunication Union Radiocommunication Sector. Some improved solutions for diffraction by multiple absorbing half-planes have also been developed [3].

3.2 Site-Specific Models for Path Loss

Site-specific propagation models are base on the theory of electromagnetic wave propagation. Unlike statistical models, site-specific 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.

1. Ray-Tracing Technique

a. Ray-Launching Algorithm

The basic procedure of a ray-tracing method is the ray-launching algorithm [2]. First, a ray is launched from the transmitting antenna (Tx), then the ray is traced to see if it hits any object or is received by the receiving antenna. When an object is hit, reflection, transmission, diffraction, or scattering will occur, depending on the geometry and the electric properties of the object. When a ray is received by a receiving antenna, the electric field (power) associated with the ray is calculated. A schematic of the ray-launching algorithm is shown in Fig.1

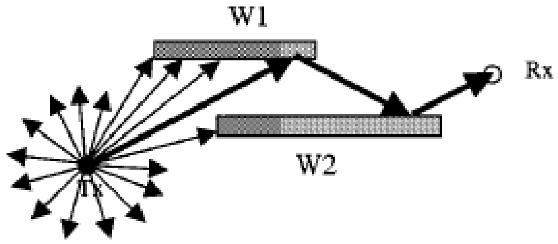

Fig. 1 Ray-Launching.

b. Image Method

The image method is a simple and accurate method for determining the ray trajectory between the transmitter (Tx) and the receiver (Rx). Fig.2 shows the basic idea of the image method. For this simple case, the image of Tx due to *W*1 is first determined (Tx1 in Fig.2). Then the image of Tx1 due to *W*2 is calculated (Tx2). Connecting Rx and Tx2, one can find a reflection point (*P*2) on *W*2. Another reflection point (*P*1) is the intersection point of *W*1 with the line connecting *P*2 and Tx1. The image method is accurate, but suffers from inefficiency when the number of walls involved is large and reflection times are high.

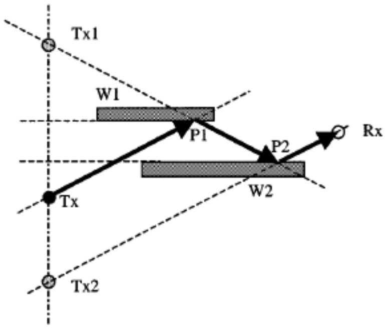

Fig. 2 Illustration of the image method.

c. Hybrid Method

Hybrid method combined the image and ray-launching methods. The ray-launching method is used to quickly identify a possible ray trajectory from Tx to Rx. When the trajectory is found, a series of walls involved can be determined. The exact reflection positions can then be accurately found by the image method. This method has the advantages of the ray-launching (efficient) and image (accurate) methods.

2. Finite-Difference Time-Domain Models

In a complicated communication environment, transmitting and receiving antennas are often 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 provides a complete solution for all the points in the map, which can give signal-coverage information throughout a given area.

3. 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 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 case 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.

IV. RESULT COMPARISON BETWEEN OUR SOFTWARE USING THE RAY-TRACING TECHNIQUE AND MEASUREMENT

The scheme of our software program is shown in Fig. 3.

The C# programming language is used to make this software. The speed of computation in this software is faster than others due to the flexibility of C#. Besides, matrices are also used in software to store the average power, a number of reflected rays and transmitted rays. It is comfortable to access and process the database. That is a reason why the results are shown fast and exactly. Furthermore, the users can modify the floor layout easily.

Table 1. A comparison of various models for path loss

Model Name	Suitable Environment	Complexity	Experimental Data	Details of Environment	Accuracy	Time
Okumura Model	Macrocell	Simple	Base on experiments	No	Good	Little
Hata Model	Macrocell	Simple	No	No	Good	Little
COST-231	Microcell (outdoor)	Simple	No	No	Good	Little
Ray Tracing	Outdoor Indoor	Complex	No	Yes	Very Good	Very Much
FDTD	Indoor (small)	Complex	No	Every detail	Best	Very Much
MoM	Indoor (small)	Complex	No	Every detail	Best	Very Much

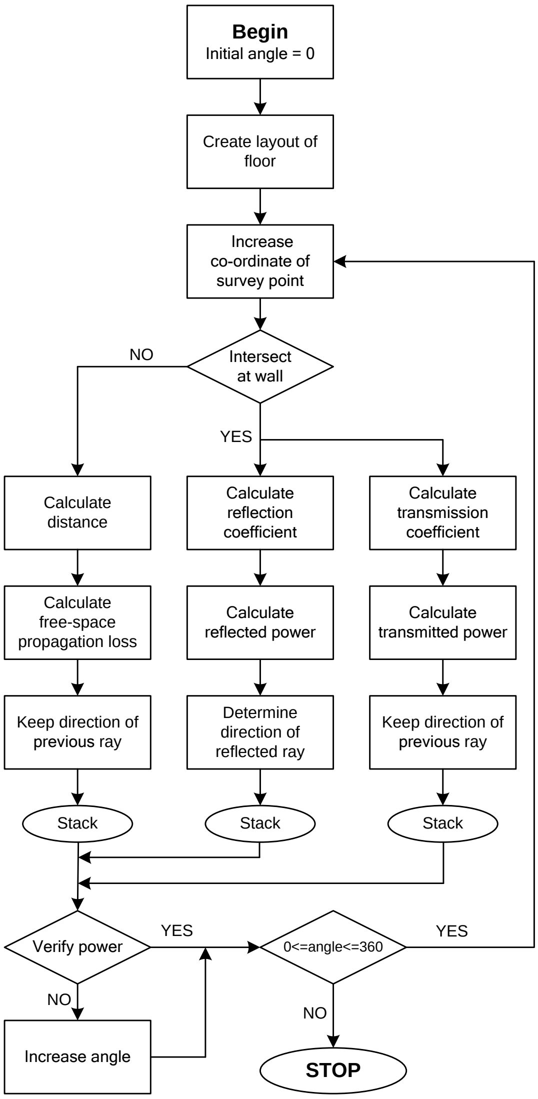

Fig. 3 A scheme of our program.

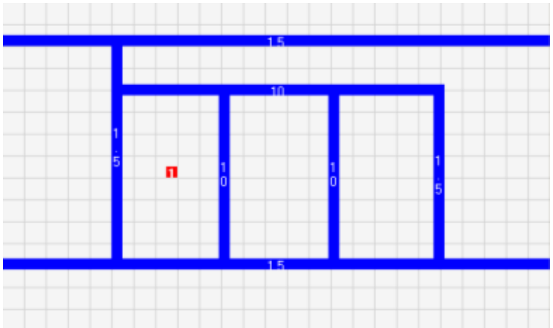

Fig. 4 Floor layout.

Fig.4 is a floor layout of the Department of Telecommunications Engineering. We can change these walls in floor layout. Walls of all rooms are made from glass (marked by number 10 - dielectric constant of glass) and cement (marked by number 1.5 - dielectric constant of cement). The transmitting antenna is located at the number 1 (see Fig.4). Transmitting power is of 1mW, measured at 900 MHz.

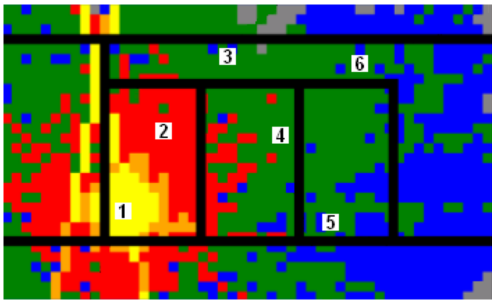

Fig. 5 Coverage map in the first scenario.

The receiving power distribution obtained by our software using the ray-tracing technique for the first scenario is shown in Fig.5. In this figure, the yellow color indicates for the strongest receiving power, while the blue one is for the weakest power (but still larger the threshold receiving power). The gray color in the figure indicates for the power below the threshold. Table 2 compares receiving powers obtained by the software and by the measurement in the first scenario. The measurement is performed in the Laboratory of Telecommunications Engineering. Generally, the results from the software and from the measurement are acceptable. The difference of prediction is about 2.5 dB over all zones.

Table 2. Receiving power at several sample points in the first scenario.

Position	Our program	Measurement
1	-30dBW	
2	-69.75 dBW	-72 dBW
3	-82.70 dBW	-80 dBW
4	-78.51 dBW	-77 dBW
5	-85.60 dBW	-87 dBW
6	-86.13 dBW	-85 dBW

In the second scenario, we will change the location of the transmitting antenna. The transmitting antenna is now located at the point number 1 (see Fig.6). Transmitting power is of 1mW, measured at 900 MHz.

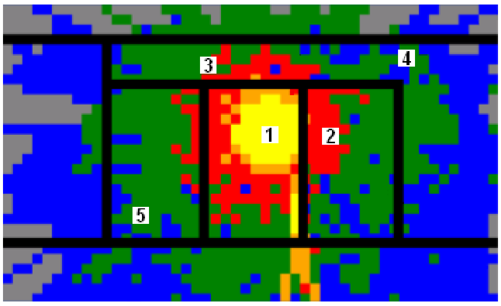

Fig. 6Coverage map in the second scenario

In the second scenario, we will see the power distribution in all zones is better than the one in the first scenario. The difference between the software and the measurement is about 1.5 dB over all zones. The reason is due to the location of the antenna. In the second scenario, the antenna is located at the center of layout. By selecting the right location of transmitting antenna, it is able to distribute power appropriately in the specific zone.

Table 3. Receiving power at several sample points in the second scenario

Position	Our program	Measurement
1	-30 dBW	
2	-67.55 dBW	-66 dBW
3	-74.83 dBW	-75 dBW
4	-79.02 dBW	-78 dBW
5	-78.48 dBW	-80 dBW

Finally, according to the simulation and measurement results, the ray-tracing technique provides accurate predictions of the signal propagation without relying on extensive measurements and speed of computation is acceptable. With these reasons, the ray-tracing technique is an appropriate selection.

V. CONCLUSIONS

In this paper, we have surveyed 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 software based on the ray-tracing technique has been developed for determining the power distribution in indoor environments. The numerical results obtained from the software agree with the measurement results. The proposed software is helpful for planning/re-planning cells in indoor wireless communications.

As a future work, this model can be extended further to include diffracted paths, which can be applied to microcellular environment where reflection and diffraction are the dominant propagation mechanisms. Furthermore, the analysis can be extended to three-dimensional geometry, which enables us to predict power coverage in multistory buildings.

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