Application and realization of ray tracing in network planning of wireless private network

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Abstract: In order to meet the business requirements of wireless private network in network planning, especially the network requirements of intelligent power private network, such as greater capacity and higher precision. In this paper, deterministic propagation model is used to simulate the network in network planning to improve the accuracy of calculation, and at the same time, must ensure the speed of the planning software. The reverse ray tracing algorithm and mirroring method are used for calculation. Simulation results show that when calculating the direct and low-order reflection paths and ignoring the high-order reflection and diffraction paths that have little effect on the results can ensure a certain calculation rate. And achieve the purpose of balance accuracy and rate.

1. Introduction
Since the beginning of the “Twelfth Five-Year Plan”, according to the construction needs of the smart grid, the coverage of the power grid needs to be extended to the residents, which puts higher requirements on the stability and security of the communication network [1]. The coverage advantage of TD-LTE network for mass terminals is obvious. It is necessary to study the application of TD-LTE network in private network.

In wireless network planning, propagation model research is the basis of coverage analysis and capacity simulation. In wireless network planning, the wireless propagation model can accurately simulate the propagation coverage of the network, providing a basis for the design and verification of wireless network planning [2]. At present, the residential users of the power private network are mainly concentrated indoors, where the environment is more complex and the calculation requirements for propagation model are higher. Therefore, it is necessary to study indoor wireless network [3].

2. Propagation model classification
According to the nature of propagation, the propagation models can be divided into two categories: empirical propagation models and deterministic propagation models.[4] Empirical model: An empirical model is a formula derived from statistical analysis of a large number of measured data. The method is simple, and it doesn't require detailed environmental information, which is easy to use, but the method estimates that the path loss is not very accurate.[5] Deterministic model: It is based on electromagnetic theory and is used to solve specific environment. The description of this particular environment is usually done by building and terrain databases. For the deterministic model, the accuracy of the environment description determines the accuracy of the deterministic model. Therefore, this kind of model requires the highest accuracy of environment description. [6].

In the indoor environment, the transmission power of electric wave propagation is relatively small and the coverage distance is relatively short. Its propagation is not related to climate, but related to the size, shape, structure, room layout and human activities of buildings, among which the influence of building materials is the largest [7].
For indoor propagation models, deterministic propagation models are usually used to obtain more accurate results. Ray tracing is one of the most widely used deterministic propagation models.

3. Ray tracing model

The ray tracing model is a deterministic propagation model. The ray tracing technique is based on the diffraction theory of geometric optics. The electromagnetic wave is abstracted into a beam of rays, and the object points that make up the object are regarded as geometric points, and the direction of the light represents the direction of propagation of the light energy. The phase, delay and power of each ray are calculated according to the theory of electromagnetic wave propagation, and then the results of coherent synthesis of all rays are calculated.

3.1 Basic principles of ray tracing

The ray tracing technique can approximate the propagation of the ray to the propagation process of the radio wave. There are two general methods for calculating electromagnetic field parameters, analytical methods and numerical methods. For the boundary value problem with less clear boundary, the numerical solution is used to obtain the numerical solution of the electromagnetic field. For the problem with clear boundary conditions and geometric rules, the analytical solution of the electromagnetic field boundary value problem can be used to obtain the analytical solution. The exact solution obtained here for the boundary value condition.

When the received power is calculated by the ray tracing method, the power of each ray is summed. The formula is as follows:

$$P_r = \sum_{i=1}^{n} P_i$$  \hspace{1cm} (1)

Where $P_r$ represents the received power and $P_i$ represents the power carried by one of the rays.

$$P_i = \frac{P_d g_t g_r (\frac{\lambda}{4\pi d^2})^2}{\prod_j R_j \prod_k T_k^2 \prod_l A_l(s',s) D_l}$$  \hspace{1cm} (2)

Where $d$ is the total length experienced by the ray from the source to the source, $P_t$ is the transmit power, $\lambda$ is the wavelength, $g_t$ and $g_r$ are the antenna gains at the transmitter and receiver respectively in the direction of the ray, $R_j$ is the reflection coefficient, $T_k$ is the representation Transmission coefficient, $D_l$ represents the edge diffraction coefficient, and $A_l(s',s)$ is the spatial diffusion coefficient used to correct the diffraction coefficient.

Reflection coefficient: For the reflection coefficients $R_d$ and $R_v$ of the horizontally polarized wave and the vertically polarized wave, the calculation formula is as follows:

$$R_d = \sin \theta - \sqrt{\epsilon_r - \cos^2 \theta} \over \sin \theta + \sqrt{\epsilon_r - \cos^2 \theta}$$  \hspace{1cm} (3)

$$R_v = \frac{\epsilon_c \sin \theta - \sqrt{\epsilon_c - \cos^2 \theta}}{\epsilon_c \sin \theta + \sqrt{\epsilon_c - \cos^2 \theta}}$$  \hspace{1cm} (4)

Where $\epsilon_c$ is the complex downlink constant of the reflective medium, expressed as:

$$\epsilon_c = \epsilon_r - j 60 \lambda \sigma$$  \hspace{1cm} (5)

Where $\epsilon_r$ is the relative dielectric constant of the reflective medium, $\sigma$ is the electrical conductivity, and $\lambda$ is the wavelength.

3.2 Ray tracing algorithm

After the scene modeling, the ray tracing technique needs to simulate the trajectory of the ray. Algorithms for calculating ray trajectories can be divided into two categories: forward ray tracing and reverse ray tracing. The most common method of forward ray tracing is the beam method, which is also commonly called the incident and rebound ray method. This method mainly starts to trace the rays from the source and sequentially traverses all possible rays to complete the forward simulation of the radio wave propagation process. The method needs to traverse all the rays, and needs to judge the receiving range of the receiving point, that is, take the receiving point as a ball to determine whether the ray passes through the ball.

The reverse ray tracing algorithm starts from the launch point and backtracks each path that can reach the source point according to the principle of geometric optics, including direct reflection, reflection, diffraction, and so on. Abstract different objects in space into plates, columns, cones, and analyze their visible faces. Calculate the arrival power, delay, phase shift, etc. of the ray after reflection, diffraction, etc. Then coherently synthesize the results of all rays. Since the path loss of multiple reflections and diffraction is large, these rays can be selectively ignored, and only the ray paths that have a large influence on the results are calculated. In the case where it is not necessary to calculate all the rays, the degree of computational complexity is reduced by several orders of
magnitude. In addition, proper partitioning of the modeling of the scene can also make the computational complexity smaller.

3.3 Modeling of the indoor environment
For the ray tracing method, it is generally necessary to obtain the specific information of the simulation scene firstly. In this paper, the scene is described mainly by the vector form of the polyhedron model. Specifically, all spatial entities are stored in the form of a polyhedron in the scene, for example, the ground can be represented by a polygon face. In this way, the number of polyhedron, the number of vertices of each polyhedron, and the vertex coordinates of each polyhedron will be stored in the final scene database. Based on this information, information such as the normal vector of the plane can be calculated as parameters for calculating the process of reflection transmission of the ray.

3.4 Tracking of the ray propagation path
In the process of ray tracing, the space can be divided to facilitate the management of the information of the obstacles, and the ray tracing process can be more efficient. The inverse ray tracing method polls the visible faces and sharps from the receiving source to generate a virtual source that can get the receiving source through reflect and diffract, and the virtual source is the starting point of the ray’s next propagation path. According to the virtual sources, a virtual source tree is established. As shown in Fig. 1, each child node of the tree represents a virtual source point. In order to ensure the running speed of the planning software, we can ignore the high-order reflection and the diffraction ray to reduce the tree’s depth.

![Figure 1 Virtual source of reverse ray tracing algorithm](image)

Establishing a ray tracing model, this paper performs three-dimensional modeling for the indoor environment. The ray will be reflected many times by the ceiling and the floor for the indoor environment is closed. Therefore, in the received power, the proportion of the power of the reflection path will increase, and objects such as furniture in the house will have a large influence to the result. For the forward ray tracing, all rays from the source should be simulated, and the more rays that are tracked, the less likely to miss an effective ray due to environmental factors. In an indoor environment, many rays are reflected or diffracted multiple times to reach the receiving source, so the tracking algorithm is more complex than the outdoor environment. The inverse ray tracing algorithm calculates the ray path that exists in reality, and the calculated magnitude is much smaller than the forward tracking, which ensures the rate of the wireless network planning.

4 Simulation examples and verification
In order to verify the feasibility of the reverse ray tracing method in wireless network planning, this section takes the indoor scene as an example and performs simulation analysis according to the scenario. The specific process is as follows.

4.1 Model and simulation environment
The indoor environment model is shown in Figure 3. According to Recommendation ITU-R P.2040-1, “Effects of Building Materials and Structures on Radio Wave Propagation Above 100 MHz”, the relative dielectric constants and conductivity of materials are shown in the table below.

| Material       | Relative interface constant | Electrical conductivity |
|----------------|-----------------------------|-------------------------|
| Concrete       | 6.48                        | 0.166                   |
| Solid wood     | 1.64                        | 0.11                    |
| Glass desktop  | 6.2                         | 0.1                     |

4.2 Analysis of simulation results
The transmitting antenna and the receiving antenna are abstracted as points, the coordinates of the transmitting antenna are $T_x(1,17,1)$, the transmitting power is set to 20 dBm, and the coordinates of the receiving antenna
are $R_x (15,1,3)$. Due to the occlusion of the cabinet, there is no direct path to the propagation path, and tracking is performed using reverse ray tracing. The results obtained are shown in Fig 2.

![Figure 2 Indoor multipath effect tracking](image)

![Figure 3 Power delay distribution](image)

![Figure 4 Planform of power distribution](image)

When the transmitting antenna coordinates are $T_x (1,17,1)$, the receiving antenna $R_x$ is arbitrary coordinates and the height is 1.5 m, the field strength distribution at different positions is as shown in Fig 4. The depth of the color represents the magnitude of the electric field intensity of the signal. The emission point is $T_x (1,17,1)$. As the signal is radiating, the electric field intensity of the signal gradually decreases. The lightest area is the location of the obstacle. Since the height of the receiving point is lower than the height of the obstacle, the color of the position of the obstacle is the lightest, that is, the electric field intensity of the signal is the smallest. Consistent with the actual situation the electric field intensity of the signal of the position of the obstacle should be the weakest.

When the coordinates of the transmission point is $T_x (1,17,1)$, select 10 points $R_1 (0,2,3), R_2 (5,7,1), R_3 (1,12,2), R_4 (11,3,3,5), R_5 (4,0,1), R_6 (7,18,2), R_7 (7,2,1), R_8 (13,17,3), R_9 (14,18,2), R_{10} (15,1,3)$. In which the first 5 points have a direct path, and the next 5 points do not have a direct path. Table 2 shows the proportion of direct reflection, primary reflection, secondary reflection, tertiary reflection, primary diffraction, higher secondary reflection and diffraction in the received power of the receiving point. Table 3 shows the power ratio of different propagation mechanisms when there is no direct path.

| Receiving point | Direct | Primary reflection | twice reflections | thrice reflecting | Primary diffraction | Higher order reflection and diffraction |
|-----------------|--------|--------------------|-------------------|-----------------|--------------------|----------------------------------------|
| 1               | 77.02  | 17.87              | 4.65              | 0.89            | 0.45               | 0.12                                   |
| 2               | 85.13  | 10.9               | 2.89              | 0.65            | 0.34               | 0.09                                   |
| 3               | 93.34  | 3.91               | 2.13              | 0.32            | 0.24               | 0.06                                   |
| 4               | 70.56  | 21.23              | 5.75              | 1.43            | 0.78               | 0.25                                   |
| 5               | 75.06  | 17.89              | 5.05              | 1.14            | 0.67               | 0.19                                   |
| Mean of proportion | 80.222 | 14.16             | 4.094             | 0.886           | 0.496              | 0.142                                  |

| Receiving point | Primary reflection | twice reflections | thrice reflecting | Primary diffraction | Higher order reflection and diffraction |
|-----------------|--------------------|-------------------|-----------------|--------------------|----------------------------------------|
| 6               | 56.95              | 27.79             | 14.07           | 0.52               | 0.67                                   |
| 7               | 58.54              | 29.43             | 10.71           | 0.54               | 0.78                                   |
| 8               | 64.76              | 22.65             | 11.2            | 0.67               | 0.72                                   |
| 9               | 48.34              | 32.34             | 17.51           | 0.89               | 0.92                                   |
| 10              | 51.54              | 31.13             | 15.69           | 0.75               | 0.89                                   |
| Mean of proportion | 56.026            | 28.668            | 13.836          | 0.674              | 0.796                                  |

It can be seen from the data in Table 2 that when there is a direct path, the power of the direct path accounts for the highest proportion of the total power. When the distance between the receiving point and the transmitting point is relatively close, the direct ray power ratio can reach more than 90%. The average power of direct power is 80.222%, the average power of primary reflection path is 14.16%. The average power of reflected path that is more than four times and the power of diffracted path that is more than two times accounts for 0.142%. It can be seen that in the indoor environment, the influence of the diffusive power on the total power is very small, but the influence on the rate of the planning software is relatively large, so it can be ignored. The sum of direct ray power and within three (including three) times reflected ray power accounted for more than 99% of the total power.

It can be seen from the data in Table 3, when there is no direct path, the power of the primary reflection path accounts for the highest proportion of the total power. And the power of the reflection within three times (including three times) accounted for more than 98% of the total power. Moreover, the simulation takes 87s when the direct
ray and reflected ray within three times (including three times) are calculated, while it takes 1431s when calculate the reflected ray within 12 times and the diffracted ray within 4 times. The speed is 16 times faster. Therefore, it can be concluded that in the wireless network planning, calculating the direct ray power and reflected ray power which setting the maximum number of times of reflection is 3. In this way, the software of network planning can not only meet the requirements of accuracy, but also greatly improve the rate of the software to achieve the purpose of balancing accuracy and rate.

5 Summary
In wireless network planning, how to improve the accuracy of the propagation model, and to increase the operating speed of the software as much as possible is a practical problem that must be faced. Considering the user usage scenarios of the power private network, the simulation of the indoor environment is very important in the network planning of the power private network. Considering the complex environment in the room, the reverse ray tracing method is an accurate method for predicting the indoor radio wave propagation model. The number of reflections that need to be calculated in the simulation can be set according to different requirements for accuracy and rate, thereby achieve the purpose of balancing accuracy and rate.

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