Research on Simulation and Test of Spatial Isolation Based on Geographic Information

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Abstract. In the process of site selection for the deployment of distributed systems, in order to solve the problem of inaccurate spatial isolation simulation results caused by the large influence of complex geographic information such as terrain and weather on the propagation of radio waves, and to solve the problem of inefficient and inefficient spatial isolation testing. This paper proposes to select suitable propagation models for different geographical information in different regions, clarifies the simulation calculation method, and proposes a test method to accurately determine the direction of the transceiver antenna for the minimum spatial isolation. By comparing and analyzing the simulation calculation results and test verification results, correction parameters such as simulation system error, atmospheric absorption loss, and geological absorption loss are proposed. This article analyzes and studies the correction value of radio wave transmission loss of S-band electromagnetic signal under different geographic information conditions such as snowfall and iron ore through an example. It can provide reference values for some of the influencing factors of electromagnetic signal propagation loss under geographic information conditions, and it can improve the accuracy of the simulation calculation results of the spatial isolation under the conditions of geographic information.

1. Introduction
At present, a distributed system with multiple functions deploys transmitting and receiving antennas in different geographical locations, and the isolation between the transmitting and receiving antennas is large enough to meet the use requirements of this type of equipment. Therefore, it is necessary to conduct a detailed survey of the specific deployment location of this type of equipment, and test the spatial isolation between the planned deployment locations to meet the requirements of equipment use. Since the organization and implementation of the space isolation test is difficult and time-consuming, it is necessary to use professional simulation tools to simulate the space isolation before the test, and then determine whether further testing is needed based on the calculation results. This can improve the efficiency of equipment deployment location survey and selection. At the same time, in order to avoid the situation that the deployment points that meet the conditions are mistakenly deleted due to the large error of the simulation calculation results, we can use the measured data to correct the simulation calculation results during the multi-point measurement process. And based on empirical data, real-time correction of errors caused by geographic information differences such as terrain changes, geological structure changes, and changes in meteorological conditions, so as to continuously improve the accuracy of simulation calculations.
2. Simulation of spatial isolation based on geographic information

Geographical information is represented by geographic data of spatial location, attribute characteristics and temporal characteristics[1]. The spatial location data describes the location of the features and determines the regionality of geographic information. Attribute characteristics include topography, geological structure, vegetation distribution, etc., which are multi-dimensional. Temporal characteristics reflect the time/period of geographic data collection or geographic phenomena, and are dynamic.

The propagation of electromagnetic waves under geographic information conditions mainly considers the diffraction and scattering propagation of electromagnetic waves under different terrain and meteorological conditions[2].

The space link loss $L$ when electromagnetic wave propagates through diffraction includes free space transmission loss $L_f$, additional diffraction loss $L_d$, shielding attenuation $SFW$, the formula is as follows:

$$L = L_f + L_d + SFW$$

(1)

Free space transmission loss $L_f = 20\log\left(\frac{4\pi D}{\lambda}\right)$ [3], $D$ is the propagation distance, $\lambda$ is the wavelength. The diffraction loss $L_d$ is determined according to the propagation model suitable for electromagnetic wave diffraction. According to the ITU Radio Regulation Recommendations, the ITU-R P.526 model is preferred among the models suitable for evaluating the diffraction effects of radio wave propagation[4]. This model mainly describes the diffraction influence of radio wave non-line-of-sight propagation and the method of field strength prediction. In addition to the diffraction caused by rugged terrain, the diffraction influence of the spherical surface of the earth is also considered in the prediction. The occlusion attenuation $SFW$ is also mainly produced by the occlusion of the signal by the terrain during diffraction propagation, and its specific value is determined by the propagation model.

The scattering and propagation of electromagnetic waves are greatly affected by topography, geomorphology and meteorological conditions[5]. The transmission influence factors include transmission distance, transceiver frequency, antenna elevation angle, scatterer height, regional distribution and climate conditions and many other factors. According to the ITU Recommendation ITU-R P.617-5 model[6], the calculation formula of the scattering loss $L_{bs}$ is as follows:

$$L_{bs}(p) = F + 22\log f + 35\log \theta + 17\log d + L_c - Y_p$$

(2)

In the formula, $F$ is the meteorological factor, the unit is dB, $F = 0.18 \times N_0 \times \exp\left(-h_s/h_h\right) - 0.23 \times dN$, $h_s$ is the altitude of the area, $h_h$ is the height of the homogeneous atmosphere, and $N_0$ is the average sea level Refractive index, $dN$ is the average annual radio refractive index decline rate;

$\theta$ —— the scattering angle, the unit is mrad;

$L_c$ —— the coupling loss between the antenna aperture and the medium, the unit is dB;

$Y_p$ —— $p \%$ the conversion factor that the time is not exceeded, the unit is dB.

The above parameters can be found in the model of the relevant ITU-R Recommendations.

In software simulation, combined with local geographic information conditions, the scattering propagation mainly considers the two scattering forms of clear sky and water vapor condensation, and the most suitable propagation model is the ITU-R P.452 model. This model is used for the prediction and analysis of microwave interference based on clear sky and water vapor condensate scattering and propagation between ground stations with a frequency of 0.1-50 GHz.

In the spatial isolation simulation, comprehensively consider the geographic information of equipment deployment, and the specific steps are as follows:
1) Clarify the spatial position data of the receiving and sending equipment. Determine the deployment location of the transceiver antenna, determine the altitude, and clarify the installation height of the transceiver antenna.

2) Establish a station model of the transceiver equipment. Determine the electromagnetic characteristic parameters of the transceiver equipment, including parameters such as transmit and receive frequency, antenna gain, and radiated power.

3) Select the radio propagation model. In the International Telecommunication Union Recommendations and the empirical formula of radio propagation, select the appropriate propagation model according to the terrain conditions.

4) Calculate the spatial isolation between the transceiver equipment. Calculate the radio link performance between the transceiver devices according to the spatial isolation calculation formula.

5) Correction of calculation results. Comprehensive analysis of geographic information related parameters, including local seasons and climatic conditions, terrain occlusion, geological structure, vegetation distribution and other revised calculation results.

In the specific implementation, the link performance analysis module of WRAP software can be used for spatial isolation calculation simulation. According to the above simulation steps, the software can select ITU-R P.526 propagation model, ITU-R P.452 model and general propagation model Detvag-90/FOI to simulate the space propagation loss, which is convenient to compare and verify the simulation results.

3. Space isolation test

The spatial isolation test is to construct a spatial isolation test system using electromagnetic signal transmitting and receiving systems, and measure the amplitude of the received signal in the transmit and receive direction of the minimum isolation. The connection of the test equipment is shown in Figure 1.

![Figure1. Schematic diagram of spatial isolation test based on geographic information](image)

In the case of no obstacles between the transmitting and receiving antennas, the minimum value of the spatial isolation measurement is generated when the transmitting and receiving antennas are aligned with each other. However, in the case of complex geographic information, there are obstructions such as mountains and vegetation between the transmitting and receiving antennas. Due to the propagation conditions of electromagnetic wave diffraction, scattering and reflection, the minimum spatial isolation is not necessarily when the transmitting and receiving antennas are aligned with each other. Therefore, under specific geographical conditions, the primary task of spatial isolation testing is to determine the minimum spatial isolation transmitting and receiving directions. The specific test method is as follows:

1) Determine the alignment direction of the transmitting and receiving antennas. According to the coordinates of the transceiver site, calculate the theoretical transmitting azimuth angle $\Phi_T$ and the
theoretical receiving azimuth angle $\Phi_R$ that the transmitting and receiving terminal is directly facing. The transmitting pitch and receiving angle are the minimum shielding angles $\theta_t$ and $\theta_r$ of the location.

2) Determine the minimum isolation transmit and receive direction. The initial azimuth angle of the transmitting antenna is $\Phi_T$, the elevation angle is $\theta_t$, the transmitting azimuth angle range is $\pm 60^\circ$, and the elevation angle range is $0-20^\circ$. First adjust the transmitting antenna angle, that is, adjust the azimuth and elevation angle in steps of $10^\circ$ within the above-mentioned angle range. Each time the transmitting angle is adjusted, the receiving antenna is based on the initial azimuth angle $\Phi_R$ and the initial elevation angle $\theta_r$, Adjust the azimuth of the receiving antenna according to a step of $20^\circ$ within the range of $360^\circ$, and record the data every time, and finally calculate the maximum signal level. The transmitting and receiving direction corresponding to this value is the transmitting and receiving direction of the minimum spatial isolation.

3) Continuous testing of isolation. Keep the minimum space isolation angle and status of the transmitter and receiver unchanged, record the level value every 5 minutes, and the test time is not less than 24 hours.

4) Calculate the degree of spatial isolation. The electromagnetic isolation between transceiver stations is calculated according to the following formula:

$$L_s = P_t + G_t L_i + G_r + G_{LNA} L_r - P_r$$

In the formula:
- $L_s$—Electromagnetic isolation between transceiver stations, dB;
- $P_t$—The transmitting power of the transmitting sub-system, dBm;
- $G_t$—The gain of the effective radiation direction of the transmitting antenna, dB;
- $L_i$—Attenuation of transmission sub-system cable etc., dB;
- $G_r$—Gain of receiving antenna, dB;
- $G_{LNA}$—Gain of low noise amplifier, dB;
- $L_r$—Receiving subsystem cable and other attenuation, dB;
- $P_r$—received power, dBm.

4. Simulation and test examples and result analysis

4.1. Test verification

The simulation and testing of three transceiver antenna deployment points in Northeast China were carried out, namely point T1/R1, point T2/R2, and point T3/R3. Among them, the transmission and reception of the point T1/R1 are not visible, the distance is 29.5 kilometers, and there are many vegetation and low mountain areas in the middle. The transmission and reception of the point T2/R2 is not visible, and the distance is 24 kilometers. There are many mountains and vegetation in the middle. Tests were carried out in clear and snowy weather. The distance between T3/R3 is 28 kilometers, which is not visible. There are many mountains and vegetation in the middle, and the two main mountains are iron mines with high iron content.

According to the spatial isolation simulation method and the above-mentioned terrain conditions, the scattering propagation model ITU-R P.452, the diffraction propagation model ITU-R P.526, and the general propagation model Detvag-90/FOI are selected for simulation respectively. The height of the transmitting and receiving antennas is 3m. The transceiver frequency is 2.364GHz. At the same time, in accordance with the above-mentioned spatial isolation test and calculation method, the spatial isolation of the three points was tested. Figure 2 and Figure 3 show the simulation and test curves of spatial isolation at point T2/R2.
Figure 2. Schematic diagram of the simulation results of the spatial isolation at the T2/R2 point

Figure 3. The test change curve of the spatial isolation at point R3/T3 in 22 hours

The simulation and test results of the spatial isolation of all points are shown in Table 1.

| Position   | Simulation isolation value (dB) | Actual test isolation value (dB) | Error between simulated maximum value and measured minimum value (dB) | Remarks                  |
|------------|---------------------------------|---------------------------------|---------------------------------------------------------------------|--------------------------|
| Point T1/R1| 203.8                           | 205.3                           | 208~220.9                                                           | Clear sky               |
|            | ITU-R P.452                     | ITU-R P.526                     |                                                                     |                          |
|            | Detvag-90                       |                                 |                                                                     |                          |
| Point T2/R2| 184.6                           | 186.1                           | 189~198.7                                                           | Clear sky               |
|            |                                 |                                 |                                                                     |                          |
|            |                                 | 192.8~202.9                     |                                                                     | Medium snow weather     |
| Point T3/R3| 196.6                           | 198.5                           | 208.5~234.6                                                         | Clear sky, there are iron mines between sending and receiving |
|            |                                 | 197.2                           |                                                                     |                          |
4.2. Result analysis

The following can be analyzed from Table 1:

1) In the case of the three propagation models, the difference between the simulation results of the spatial isolation of each propagation model is no more than 2dB; among them, ITU-R P.526 is selected as the propagation model in the northeastern region of my country as the simulation value and the measured result of the spatial isolation Minimum difference.

2) Under clear sky conditions, the difference between the simulated maximum value of the spatial isolation and the measured minimum value is about 3dB. The difference between the simulation and test results of the spatial isolation proposed in this paper is basically fixed, and the difference between the simulated maximum value and the measured minimum value is no more than 3dB.

3) At the same sending and receiving point, under two different weather conditions, clear sky and medium snow, the difference in spatial isolation test results is about 4dB. Therefore, it is preliminarily inferred that the propagation loss of electromagnetic signals in snowy weather is about 4dB than that in sunny weather.

4) The difference between the simulation result of the T3/R3 spatial isolation of the point and the measured minimum is about 10dB. The reason is that the electromagnetic signal absorption loss of the iron mine between the receiving and sending points is not considered in the simulation. Therefore, the high metal content of the mountain and other obstructions has a greater impact on the electromagnetic signal propagation loss. It is preliminarily inferred that the geological absorption loss caused by the ferrous metal mountain is about 10dB.

5. Simulation model revision

By comparing and analyzing the simulation calculation results and the test verification results, it can be seen that in order to correct the accuracy of the simulation calculation results, the simulation calculation model should introduce parameters such as simulation system error, atmospheric absorption loss, and geological absorption loss. Formula 1 can be revised as:

\[ L = L_f + L_d + SF_w + L_e + L_w + L_a \]  \hspace{1cm}\text{(4)}

- \( L \) is the transmission loss in the case of electromagnetic wave diffraction;
- The meanings of the parameters of \( L_f, L_d \) and \( SF_w \) are consistent with formula 1;
- \( L_e \) is the simulation system error, which is the error between simulation calculation and actual test, which can be obtained from the empirical data of multiple simulations and actual tests;
- \( L_w \) is the atmospheric absorption loss. The local weather conditions, such as the absorption, reflection, and refraction loss of electromagnetic waves by rainfall and snow, are considered in the simulation calculation, and it is calculated based on empirical data.
- \( L_a \) is the geological absorption loss, which mainly considers the influence of the geological conditions between the transmitting and receiving antennas on the electromagnetic wave absorption. It is determined by the geological conditions between the transmitting and receiving devices, including the metal type and content of the shielding body, which can be calculated and determined based on empirical data.

According to the analysis of the test results in Section 4.2, the simulation system error \( L_e \) is about 3dB; the atmospheric absorption loss \( L_w \) in the S-band under snowy weather is about 4dB; the geological absorption loss in the S-band under the obstruction of iron ore between the transmitting and receiving antennas \( L_a \) is about 10dB.
6. Conclusion
Geographical information such as topographical conditions and meteorological conditions has a high degree of complexity in the influence of electromagnetic signal propagation. Before the spatial isolation test, it is necessary to select appropriate software and simulation methods to simulate the spatial isolation and influence the space. The geographic information impact factor of the isolation simulation result is revised to improve the accuracy of simulation calculation and break through the limitation of relying solely on the propagation model for simulation.

This paper proposes a simulation calculation method for the spatial isolation under actual geographic information conditions, selects an appropriate propagation model, and proposes an accurate test method for the minimum isolation transmission and reception angle. Through the comparison and analysis of the simulation calculation results and the test verification results, the simulation system error, atmospheric absorption loss, geological absorption loss and other correction parameters are proposed, and the simulation results are corrected in close combination with the actual local geographic information, which improves the accuracy of the simulation calculation. It provides theoretical support for the simulation calculation of space isolation.

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