Path Analysis of Diffraction Model in Mountainous Environment

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ABSTRACT

This paper analyzes the wireless transmission path model in mountainous environments. Diffraction propagation is the main method of electromagnetic wave propagation in mountainous environment. This paper first analyzes the mountain diffraction loss model based on fresnel integral and discusses the expansion formula of fresnel integral, and applies the range to single peak diffraction formula and double diffraction. Last discussed the relationship between the frequency, distance and height of radio wave propagation when the receiver sensitivity is 150dB, and finally the establishment of the diffraction model, which improves the process of radio wave prediction effectiveness.

KEYWORDS
Radio Wave Propagation, Path Loss, Propagation Gap.

INTRODUCTION

When communicating in a mountainous environment, the performance of wireless communication systems will be affected by varying degrees of geographic environment. The electromagnetic waves emitted by the antenna will be affected by the high and low mountains, resulting in scattering, reflection, diffraction, refraction and other mechanisms that cause electromagnetic interference. There are great randomities and difficulties in predicting. With the rapid development of wireless communication systems, in order to make the electromagnetic interference prediction work between systems more systematic, we must model the electromagnetic environment. Electromagnetic compatibility environment prediction is achieved by studying the propagation characteristics of radio waves.

In the prediction of the mountain environment, the attenuation of the signal is mainly derived from the diffraction loss of the mountain. Peak-to-peak diffraction is a very good model for calculating the propagation loss of radio waves in mountain communications. There have been many methods in previous studies on the diffraction of many mountains. The author of[1] equates all peaks to one mountain. The calculation method of single-peak diffraction is simple, but the error is large. Now, it is no longer used; in[2], the authors describe a relatively high method of extending...
mountain diffraction to bimodal diffraction. The method of[2] is superior to[1], but still provides the results of the results provided. After the 10dB error, another method was proposed in[3] Deygout, which proposed the concept of main peak and sub-peak, extending the peak diffraction to three peaks or more, and improving the accuracy, the range is ±3dB. Within, the Deygout method is widely used. These methods are all previous studies on the diffraction loss of the mountain range and do not involve the effect of radiation on the total signal at the receiving end.

Because the prediction of the results must be considered when using electromagnetic compatibility software for prediction, on the one hand, the prediction results should have practical reference value.

THEORETICAL ANALYSIS

Radio waves propagate in the following ways: direct waves, ground waves or surface waves, reflected waves in the troposphere, reflected waves and refracted waves in the ionosphere. Figure 1 shows the possible ray paths between the transmitting and receiving antennas in a mountainous environment, h representing the height of the mountain, and the distance between the d1 and d2 transmitting and receiving antennas and the mountain. And the two transceiver antennas are equipped with the same.

In the mountainous environment, the main prediction model for radio wave propagation is the diffraction model. When there are obstacles between the transmitting and receiving antennas, the main propagation mechanism is diffraction propagation. However, when the transmitting and receiving antennas are higher than the obstacles, the main propagation mechanisms are free space propagation and diffraction propagation. Therefore, when predicting the propagation of radio waves in a mountainous environment, the main formula is expressed as:

\[ L_D = L_{\text{diff}}(d, f) + L_d \]  

(1)

\( L_D \) is the diffraction loss in the presence of diffraction, and \( L_d \) is the diffraction loss. The influence of terrain on electromagnetic wave propagation is not considered in(1). Therefore, according to the influence of the peak height on the diffraction loss given in[4], we study the influence of the height of the mountain on the path loss.

In calculating the wave propagation loss, in order to consider the influence of the obstacle, the gap v is introduced, which represents the relationship between the vertical height between the transmission and reception antenna and the obstacle and the fresnel zone, \( v = \sqrt{2} \times \frac{h}{r} \), r is the fresnel radius.(2) gives an alternative formula for diffraction loss, which ranges from \( v > -0.78 \), without completely covering the first-order fresnel zone. At the same time, because the calculation of fresnel integral is complicated, and it is not easy to see the transmission law of radio wave propagation, the equation(2) is further simplified, and the equation(3) is obtained. The difference between the equation and the equation(2) is only 1 dB. However, the scope of application has not been expanded, and it cannot cover the first-order fresnel gap. Therefore, it is still necessary to perform a quadratic expansion of the formula to obtain the formula(4).
The extended range of the equation after the expansion is:
\(-1.8 < v < 1.5\), which perfectly covers the first-order Fresnel clearance.

\[
L(v) = 3.01 - 10 \times \log((1/2 - C)^2 + 1/2 - S^2)
\]  
(2)

\[
L_2(v) = \begin{cases} 
6 + 8v & -0.78 < v < 1.3 \\
12.9 + 20 \log(v) & v \geq 1.3 
\end{cases}
\]  
(3)

\[
L_3(v) = \begin{cases} 
5.7 + 9v + v^2 - 1.4v^3 & -1.8 < v < 1.5 \\
12.9 + 20 \log(v) & v \geq 1.5 
\end{cases}
\]  
(4)

The schematic diagram of multi-peak diffraction principle is show in Figure.2, 
S, R respectively represent the transmitting and receiving antennas, \(h_1\) represents 
the height of the left front \(M_1\), and \(h_2'\) represents the relative height of the right 
peak \(M_2\). \(a, b, \) and \(c\) represent the distance from the transmitting antenna to the left 
front, the distance between the two peaks, and the distance from the right peak to 
the receiving antenna. When calculating the diffraction loss process, the most 
important thing is to calculate the effective height of the secondary peak, and the 
total diffraction loss is the superposition of the main peak diffraction loss value and 
the secondary peak diffraction value calculated by the effective height.(5) and(6) 
give the calculation formula for double diffraction.

When the left is the main mountain:
When the right is the main mountain:

\[ L_d = f(d_1 = a, d_2 = b + c, h = h_1) + f(d_1 = b, d_2 = c, h = h_2 - ch_1/(b + c)) \]  \hspace{1cm} (5)

In practical engineering applications, due to the blocking of the mountain, the electric wave will be diffracted during the propagation process. When calculating the diffraction loss, if the wavelength of the electromagnetic wave is too small relative to the height of the mountain, the diffraction loss is very large, and the diffraction field does not affect the sensitivity of the receiver. At this time, it is not necessary to calculate the diffraction loss. In order to improve the efficiency in engineering calculation, this paper simulates the limit height of the peaks that can be diffracted by the frequency and the diffraction wave in the diffraction propagation, and establishes the propagation model of the frequency and the diffraction height.

RESULTS AND ANALYSIS

SINGLE KNIFE-EDGE DIFFRACTION

First, the frequency and peak height under the simple scene, that is, the case where there is only one mountain in the propagation path, is modeled. Figure 3 and 4 are plots of the clearance of the single peak diffraction loss equation.

Figure 3 is the path loss value calculated by fresnel integral in equation(2). Figure 4 shows the comparison between the path loss calculated by the first expansion formula and the secondary path loss expansion formula and the loss value calculated by fresnel integral. It can be found that the gap can be well matched. In the case where the gap is greater than -1, the calculation of path loss is performed by using equation(4) in the following work.

Figure 3. Path loss calculated by Fresnel integral.
Figure 4. Path loss calculated by fresnel integral, first-order path loss expansion formula and second-order path loss expansion formula.

Figure 5. Variation of path loss with height in different frequencies.

(a)  

(b)
The simulation result is shown in Figure 5, it shows the relationship between the height and frequency of the peak when the signal receiving sensitivity is 150dB at very high frequency. The distance is 11Km. It can be seen that the very high frequency has a strong diffraction ability under this condition and can bypass the mountain. The minimum height is 150m. The simulation value is fitted to obtain the height is 150m. The simulation value is fitted to obtain the equation (7), and the path model of the very high frequency band is established. The unit of the frequency is MHz, the unit of height is m, and the root mean square error of the model and the simulation result is 0.025.

Figure 6. The relationship between height and frequency in path loss.

\[ h = 323 \exp(-0.01656f) + 248.1 \exp(-0.001558f) \]  

(7)

DOUBLE KNIFE-EDGE DIFFRACTION

The frequency and diffraction limit height in the single-peak diffraction loss model is discuss above. In the double diffraction, the gap range of the original formula limits the calculation range of \( h_2 \). The expansion formula greatly increases the calculation range of \( h_2 \) and improves the path loss calculation accuracy. Now this formula is applied to the multi-peak diffraction case for simulation verification.
The simulation result is shown in Figure 7. When the radio wave transmission distance is 20 km, the height of the left peak is 100 m. There are two obstacles between the transceiver antenna, shows the relationship between the height of the mountain and the path loss. It can be seen that in the case of frequencies of 100 MHz, 200 MHz, and 300 MHz, the diffraction height of the mountain is greater than 200 m, and the result conforms to the law of (7). Therefore, the equation can be applied to engineering practice to predict radio wave propagation to improve prediction efficiency.

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