Calculation Method of Field Strength in the Case of Side Obstacles

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Abstract. Aiming at the problem of side obstacles on the transmission path, an algorithm for more accurate prediction of field strength has been proposed. The algorithm uses the slant profile which is determined by the antenna line and the minimum Fresnel radius to gather the information of the side obstacles, determine the Fresnel clearance and calculate the diffraction loss. The simulation results show that the side obstacles can produce the diffraction loss in the radio wave propagation as same as the vertical obstacle can, and verify the correctness and rationality of the attenuation calculated by the method in the case of the side obstacle.

Keywords: Radio wave propagation · Field strength prediction
Side obstacles · Propagation attenuation

1 Introduction

In free space, the propagation of electromagnetic waves is a relatively simple natural phenomenon, but the propagation prediction of surface electromagnetic waves is a relatively complicated process because of the diversity of the surface environment. The propagation of electromagnetic waves in different ground environment also has a different process [1]. The ITU-R P.526 model [2] mainly calculates the loss of radio wave propagation based on the vertical profile of the ground, but can not obtain the information of the side obstacles. However, the propagation of electromagnetic waves in space is not just presented in the vertical section, which leads to deviation of propagation prediction. In view of this problem, this paper considers the existence of side obstacles on the transmission path, and provides a better way to predict the wireless communication field strength.

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2 Basic Theory

2.1 The Spatial Fresnel Zones of Wave Propagation

The main channel of the radio wave propagation is not a straight line, but a rotating ellipsoid. Thus, even though the obstacle does not block the geometric rays between the two points, they have entered the first Fresnel zone. At this point, the field strength of the receiving point has been affected, so the propagation cannot be regarded as free space propagation between the two points [3]. In practical engineering applications, it can be assumed that the waves propagate freely between the two points as long as at least 55% of the first Fresnel zone, which is called the minimum Fresnel zone, is not blocked.

First Fresnel radius:

$$R_1 = 550[\frac{d_1 d_2}{(d_1 + d_2)f}]^{1/2} \tag{1}$$

Minimum Fresnel radius:

$$R_0 = 0.577 R_1 \tag{2}$$

In the formula, f is the frequency (MHz); d_1 and d_2 are the distance (km) from the point to the transmitter and the receiver on the elliptical radius.

2.2 ITU-R P.526 Model

The distance between the straight line connecting the two ends of the path and the highest point of the ground obstacle is defined as the Fresnel clearance h (Fig. 1). When the line is below the obstacle, h is positive ((a) on Fig. 1) and the radio has a large diffraction loss. When the line is above the obstacle, h is negative ((b) on Fig. 1). When $-1 < h / R_0 \leq 0$, part of the minimum Fresnel zone is blocked, but it still generates a large diffraction loss. When $h / R_0 < -1$, the minimum Fresnel zone is not blocked, so the receiving point receives the free space field strength [4, 5].

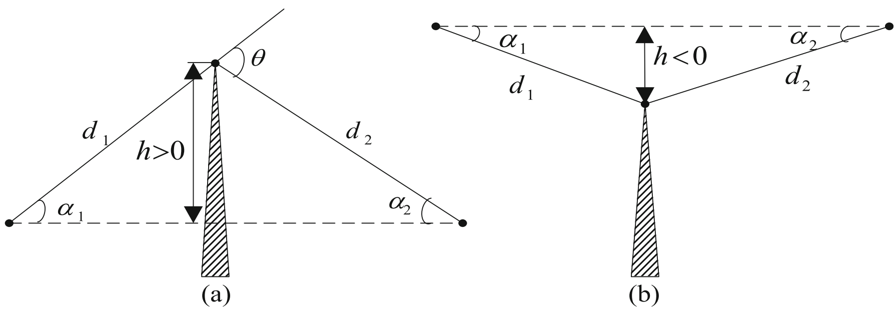

Fig. 1. Single knife-edge diffraction

V is the normalized geometric parameter of the marker obstacle:

$$v = 0.0316h\left[\frac{2(d_1 + d_2)}{\lambda d_1 d_2}\right]^{1/2} \tag{3}$$

In the formula, h is the Fresnel clearance (m); d_1 and d_2 is the distance (m) between the top of the obstacle and the ends of the path; λ is the wavelength (m) (Fig. 2).

The relationship between the diffraction loss $J(v)$ and v is [6]:

$$J(v) = \begin{cases} 6.9 + 20\log\left(\sqrt{(v-0.1)^2+1} + v - 0.1\right) & v > -0.78 \\ 0 & v \leq -0.78 \end{cases} \tag{4}$$

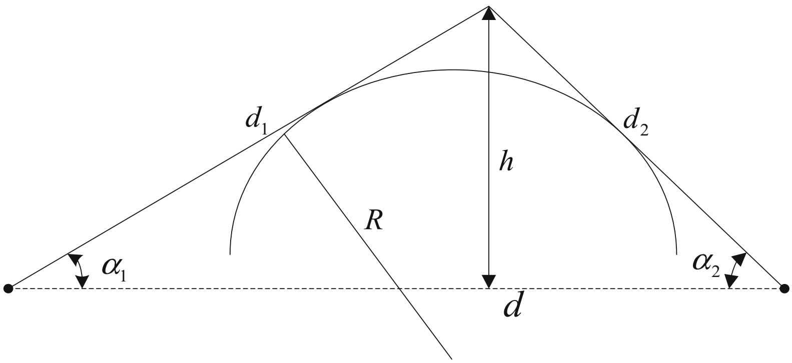

Fig. 2. Single rounded diffraction

The diffraction loss for a single rounded obstacle is [8]:

$$\begin{cases} L_v = v_0(a - H_c/H_0) \\ v_0 = 14.42 + A_v|u - 1.4|^{1.5} - 20\lg u \\ H_0 = -F_1/\sqrt{3} \end{cases} \tag{5}$$

Where:

L_v is the diffraction loss (dB) for the single rounded obstacle.
v_0 is the diffraction loss (dB) when $h = 0$.
F_1 is the first Fresnel radius (m).
H_c is the Fresnel clearance (m).
u is the terrain parameter.

Table 1. A_v relationship with u

u	0.6–0.79	0.8–1.09	1.1–1.9	1.91–2.2	2.21–2.9
Av	5.5	3.3	2.0	1.8	1.6

2.3 Side Obstacle

As shown in Fig. 3, there is an obstacle on the side of the transmitter *T* and the receiver *R*'s connection path, which is adjacent to the vertical profile of the propagation path, causing interference to the propagation of the side waves. The wave produces a diffraction attenuation when it travels on the side of the path. So the obstacle is called the side obstacle (Table 1).

3 Calculation Method of Wave Diffraction Loss in the Presence of Side Obstacles

Radio waves are propagated in a three-dimensional space, not only in the transmitter and receiver path profiles. On both sides of the path of the transmitting and receiving antenna, there may be obstacles in the first Fresnel zone, which affect the propagation of the radio waves. The vertical profile on the propagation path does not contain information about the side obstacles. Therefore, the calculation of the attenuation of the side obstacles is required to analyze the geographic information on the slant profile [7].

3.1 Analysis of Ground Type

The ground type analysis mainly determines whether there is an obstacle in the vertical cross section of the transmission path by comparing the terrain irregularity parameter Δh with the first Fresnel radius maximum value $R_{\max}$ in the propagation path. Specific steps:

1. Calculate Δh. The terrain irregularity parameter Δh is a parameter that characterizes the change of part or all of the ground height on the propagation path. It is usually defined as the difference between more than 90% of the terrain height and more than 10% of the terrain height when the path specified part is sampled at equal intervals.
2. When $\Delta h > 0.1R_{max}$, it is consumed that one or more isolated obstacles in the terrain profile of the propagation path. In this case, it should be calculated according to the ITU-R P.526 model. At this point the impact of side obstacles is small. Even if $\Delta h \leq 0.1R_{\max}$, the propagation path could not simply be thought as the smooth earth. Because it is not possible to determine whether there is an obstacle in the first Fresnel zone, it is necessary to decide whether there are side obstacles [9].

3.2 Determination of Side Obstacles

The main channel of the wave propagation is an ellipsoid whose focuses are the transmitting and receiving antenna. β is a flat in the ellipsoid that contains the straight line connecting the two ends of the path and has the largest projection of the ellipsoid on the ground. Combined the geographic information on the vertical profile of the propagation path with the slope β to determine whether there is an obstacle in the first Fresnel zone. There are many sampling points on the propagation path of the transmitter and the receiver. The set of all points with the minimum Fresnel radius from the sampling points make the projection of the minimum Fresnel zone boundary. Since the minimum Fresnel zone is the extreme distance of the obstacle occlusion, it is stipulated that there is a side obstacle in the smallest Fresnel zone when the elevation value of the boundary projection coordinates is larger than the antenna's connection height of the corresponding sampling point. Specific steps:

1. Take the same interval sampling method to get the coordinates of each point on the path when we know the location of the transmitter T and receiver R. Take a point a, and we can get the coordinates of the point b whose vertical distance from a is R_0. It is indicated that there is an obstacle in ab's section when b's elevation value H_b is larger than the height of the antenna connection T_a at point a, as shown in Fig. 3.
2. We can get the ab's profile data, when we know the location coordinates of point a and point b. According to the analysis of the ground type, there are no obstacles in the vertical section of TR, so the elevation data of the point a is smaller than the antenna height T_a. There must be a point on the ab's section with the same height of T_a because of the continuity of the elevation value of the terrain. And the distance from this point to point a is the Fresnel clearance h of the point. Or else $h = 0$, if there are no obstacles.
3. And so on, we can calculate the Fresnel clearances corresponding to each point on the path. The set of all Fresnel clearances make the projection of the side obstacle on surface β, as shown in Fig. 4. Thus, the path profile analysis for the side obstacle can be equivalent to the analysis on the vertical profile.

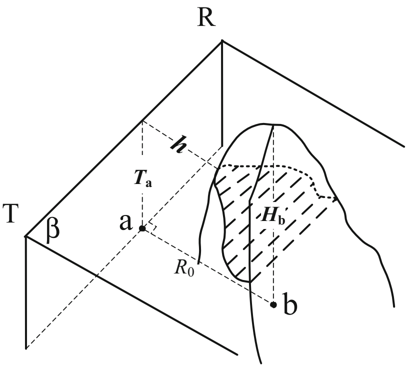

Fig. 3. Side obstacles diffraction

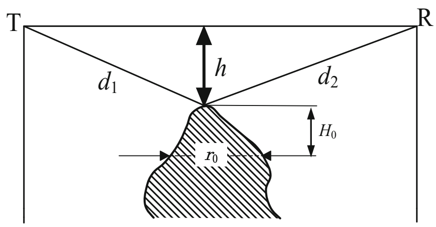

Fig. 4. Analysis of side obstacles profile

3.3 The Shape and Number of Side Obstacles

As the ITU-R P.526 model, isolated obstacles are divided into two types: blade shape and circle. The obstacle type is determined by the terrain parameter u. If $u \geq 3$, it is the ideal blade shape. If $u < 3$, it is a circular obstacle [10]. The mathematical expression for terrain parameter u calculation is:

$$u = 2.02[\frac{d_1 d_2}{(d_1 + d_2)r_0}]^{\frac{2}{3}} \tag{6}$$

In the formula, d_1 and d_2 are the horizontal distance from the vertex of the obstacle to the transmitter and the receiver. The meaning of the parameter r_0 is the width of the obstacle, which is at the distance H_0 below the vertex of the obstacle, in the direction of the connection path of the transmitting and receiving antenna, where $H_0 = R_1/\sqrt{3}$ (R_1 is the first Fresnel radius).

Unlike the vertical obstacle, since the side obstacle does not have continuity between various obstacles, it does not have to take into account the multimodal situation. As long as the minimum Fresnel zone in the propagation path is not blocked, it can be considered as free space propagation. However, the superposition of obstacles on both sides of the antenna will be considered. Specific steps:

1. Find the maximum position of the path in the lateral section, that is, the maximum position of the Fresnel clearance ($h < 0$, h is the largest distance from the obstacle recently, and the diffraction loss is the largest) as the main peak of the topographic profile curve.
2. Extend H_0 horizontally in the main peak. And do a vertical section paralleling to the antenna connection over the point. Compare the height to the antenna connection height, and take the higher part to determine the width r_0 and type of obstacle (Fig. 4).
3. Look for obstacles on both sides of the antenna connection. Calculate and sum the diffraction loss.

3.4 Loss Calculation of Various Situations

The wave propagation attenuation includes both the free space attenuation L_{bf} and the side obstacle diffraction attenuation L_s. Total attenuation L is:

$$L = L_{bf} + L_s \tag{7}$$

The Free Space Attenuation. The free space attenuation can be calculated by the free space attenuation formula, which is modified by the empirical data in the COST-231 model [11]:

$$L_{bf} = 42.6 + 20 log f + 26 log d \tag{8}$$

In the formula, f is the frequency (MHz); d is the transmission path distance (km).

The Side Obstacle Diffraction Attenuation. Calculate the Fresnel clearance h of the main peak of the side obstacle and the terrain parameter u to determine the type of obstacle. The formulas (3) and (4) are for the single knife-edge obstacle and the formula (5) is for the circular obstacles. Finally, calculate the total propagation attenuation.

4 Simulation Verification

Construct two simulation terrains which are in the case of the vertical obstacle and side obstacle respectively. Their profiles are the single peak blade obstacle, whose Fresnel clearance is 5 m and locate in the midpoint of the propagation path. Initialize parameters: set the transmission antenna's height h_t and receive antenna's height h_r to 15 m, frequency f to 460 MHz, and the transceiver antenna distance to 1500 m. The minimum Fresnel radius at the midpoint is calculated to be 9.42 m, so diffraction attenuation is bound to occur. Compare the wave propagation attenuation of the vertical and the lateral obstacle respectively.

The wave propagation attenuation of the vertical obstacle based on the ITU-R P.526 model and the lateral obstacle based on the proposed algorithm are shown in Table 2. Compare them with free space attenuation. It can be seen from Fig. 5:

1. In the vicinity of 800 m, the attenuation of radio waves increases dramatically because of the presence of obstacles nearby, resulting in diffraction loss. On the whole, the attenuation of the radio waves increases with the increase of the path distance, and the change trend is in accordance with the actual attenuation's characteristics.
2. When the vertical obstacle and side obstacle have the same Fresnel clearance, the two attenuation curves are basically consistent. It is shown that, in the process of the radio wave propagation, the side obstacle will block the first Fresnel zone and produce diffraction loss as the vertical obstacle will do.
3. The Fresnel clearance of the vertical obstacle calculated by the ITU-R P.526 model and the Fresnel clearance of the lateral obstacle calculated by the method are −4.9682 m and −4.9364 m, when the ideal Fresnel clearance is 5 m, and the resulting diffraction loss are 2.3092 dB and 2.3311 dB. The data of the two groups and the attenuation curve are basically consistent, which proves the correctness of the method.

Table 2. Path parameters and attenuation prediction results

Name	In vertical case	In lateral case
Transmission path length d (m)	1500	1500
Fresnel clearance h (m) at the vertex of the obstacle	−4.9682	−4.9364
Obstacle diffraction attenuation L_s (dB)	2.3092	2.3311
Path propagation in the vertical direction L_{bf} (dB)	115.1781	115.1781
Total attenuation of radio wave propagation L (dB)	117.4872	117.5091

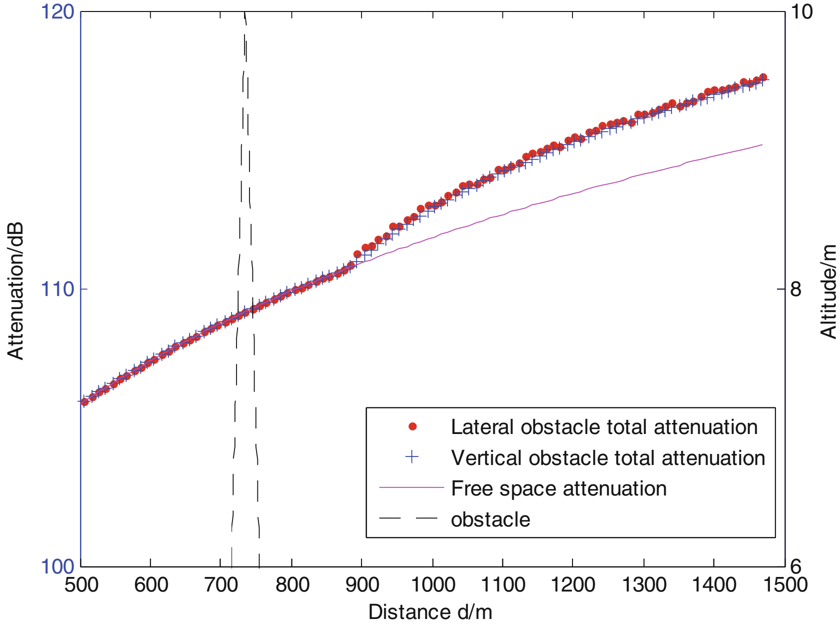

Fig. 5. Contrast of total attenuation under three kinds of conditions

5 Conclusion

On the basis of ITU-R P.526 model, this paper presents an algorithm to calculate the diffraction attenuation of side obstacles. By analyzing the geographic information of the obstacle on the oblique section, we can determine the type and number of the side obstacle, and then calculate the diffraction attenuation. Simulation results show that the algorithm is feasible and reasonable. In the process of radio wave transmission, especially under the condition of irregular terrain, this method can accurately analyze and predict the loss of electromagnetic wave.

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