Research Article

A Study on the Diffraction Correction Prediction of Electromagnetic Field Intensity Based on the Method of Estimating Aerial Access Network Signal

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Field strength is a typical indicator of air access network signals, and the prediction of field strength has important reference significance for the estimation of aerial access network signals. However, many factors affecting the field strength, such as path, terrain, sunshine, and climate, increase the computational complexity, which greatly increases the difficulty of establishing an accurate prediction system. After persistent research by researchers in recent years, the ITU-R P.1546 model has gradually become a point-to-surface forecasting method for ground services recommended by ITU for ground operations in the frequency range of 30 MHz–3000 MHz. In view of the characteristics of electromagnetic signal propagation in mountainous environment, the influence of diffraction is also considered in this paper. Based on more accurate scene information such as actual terrain, the prediction calculation of electromagnetic signal propagation in a mountainous environment is proposed by using the corrected ITU-R P.1546 model. In addition, the influence of the actual terrain is taken into account to correct the relevant parameters, and the predicted results are compared with the measured data. The results indicate that field strength prediction results of the ITU-R P.1546 model based on the diffraction effect correction proposed in this paper in specific physical areas have better performance than those of the traditional ITU-R P.1546 model. Among them, the determination coefficient between the measured data and the predicted results is 0.87, the average error is 5.097 dBμV/m, and the root mean square error is 6.6228 dBμV/m, which proves that the ITU-R P.1546 model based on the corrected model is effective in the prediction of electromagnetic field intensity in the actual mountainous environment.

1. Introduction

As the air access network becomes more and more widely used, the signal estimation of the air access network becomes more and more important. Field strength is a typical indicator of aerial access network signals, so the prediction of field strength has important reference significance for the estimation of air access network signals. However, due to the numerous electromagnetic propagation scenarios, it is difficult to find a unified electromagnetic propagation model that can meet the requirements of all propagation modes, all frequency bands, all geographical environments, and all meteorological environments because of the numerous scenarios of electromagnetic propagation prediction and the variable requirements of prediction speed and accuracy. In general, the basic model should be selected according to the specific needs because of the different adaptations of various models to the terrain [1]. The similarities and differences of scenes are mainly reflected in the propagation path, such as ground-ground, ground-air, air-air, and earth-space [2, 3]. From the perspective of propagation mode, it is generally divided into several types, such as diffraction, scattering, direct radiation, refraction, and reflection, and the basic model calculates one or more combinations of them [4, 5]. From the perspective of frequency band, it can be generally divided into long wave, medium wave, short wave, ultrashort wave, microwave,
millimeter wave, etc. [6] The application range of the model can be limited to a single frequency band or across multiple frequency bands [7]. From the perspective of geographical environment, it is generally divided into low-lying hills, plains, mountainous areas, cold and warm fresh water, cold and warm seawater, forests, deserts, tundra, etc. [8, 9] The application scope of the models can be limited to a single geographical environment or simultaneously adapt to a variety of geographic environments [10].

As for the propagation prediction model of electromagnetic signals in the 30 MHz to 3000 MHz frequency band in the mountainous area and in the propagation path of ground-ground, the main basis has been the ITU-R P.370 mode in the past 50 years (1951-2001) [11, 12]. In addition, ITU-R P.1146 and ITU-R P.529 models were also applied to varying degrees on the corresponding period [13]. In the process of using ITU-R P.370, ITU-R P.1146, and ITU-R P.529 models, even if similar or even equal conditions are given, the prediction results also vary greatly [14].

In 2001, through the inheritance and integration of ITU-R P.370, ITU-R P.529, ITU-R P.1146, and other models, ITU-R Study Group 3 launched the ITU-R P.1546 model (the latest version is ITU-R P.1546-5 at present), which organically integrates ITU-R P.370, ITU-R P.529, ITU-R P.1146, and other models, forming a new forecast system [15, 16].

The ITU-R P.1546 propagation model is suitable for a point to area prediction, with the frequency range of 30 MHz to 3000 MHz, the distance range of 1-1000 km, the height of the transmitting antenna of lower than 3000 m, and propagation horizon d of 15 km. The application range of the model can be limited to a single frequency band or across multiple frequency bands, such as millimeter wave, etc. [6] The application range of the model can be limited to a single frequency band or across multiple frequency bands [7].

2. Materials and Methods

This section should contain sufficient detail so that all procedures can be repeated. It may be divided into headed subsections if several methods are described.

2.1. Overview of the ITU-R P.1546 Model

In the calculation of field intensity, the ITU-R P.1546 model has three main elements: transmitter antenna height, receiver antenna height, and clearance angle [25–27]. The value of the transmitting antenna height 

$$h_t$$

is related to terrain, propagation path, and sight distance. The effective height 

$$h_{e}$$

of the transmitting antenna in the land path is within 3–15 km (d) from the transmitting antenna to the receiving antenna path, which is higher than the average terrain height of the ground. The 

$$h_r$$

of the sea surface path is the altitude of the antenna. Under the condition of land propagation path, the antenna height 

$$h_t$$

and propagation horizon 

$$d$$

must meet the following formula:

When the distance 

$$d < 15 \text{ km}$$

and there is no topographic data,

$$h_t = h_{e}, \quad d \leq 3,$$

$$h_t = h_{e} + (h_{e} - h_{e})(d - 3) \frac{12}{d}, \quad 3 \leq d \leq 15.$$  

(1)

When the topographic data is known,

$$h_t = h_{r}, \quad d > 15 \text{ km},$$

(2)

where 

$$h_t$$

is the antenna height above the average terrain height between 0.2 and 

$$d$$

(km) and 

$$h_r$$

is the antenna height above the earth. When 

$$h_t$$

is one of 10, 20, 37.5, 75, 150, 300, 600, and 1200 m, it can be calculated by

$$E = E_{\text{inf}} + \frac{(E_{\text{sup}} - E_{\text{inf}})}{\lg \left( \frac{h_t}{h_{\text{inf}}} \right)} \lg \left( \frac{h_{\text{sup}}}{h_{\text{inf}}} \right) d B \left( \frac{\mu V}{m} \right),$$

(4)

where 

$$h_t$$

is the height of the transmitter antenna and 

$$h_{\text{inf}}$$

is the average height of the spread path. When the height of the receiving antenna is 

$$h_r$$

(m), the reference field strength value is given by the land curve or table. When 

$$h_r$$

is the lowest of 10 m, it corresponds to open areas such as suburbs. Height 

$$h_2$$

represents the covering height of the ground around the receiving antenna. When the actual receiving antenna 

$$h_2$$

is different from 

$$h_r$$,

the correction terms related to the receiving environment need to be calculated. In order to facilitate the implementation of computer processing, the calculation method of correction term is further optimized and improved in the 1546 model, and the calculation flow chart is provided. For example, in the open area, the correction amount cor is expressed as

$$\left\{ \begin{array}{l} \text{cor} = K_{h_2} \frac{\h_2}{h_r} \\
K_{h_2} = 3.2 + 6.2 \lg (f), \end{array} \right.$$

(5)

where it is set as 10 m.
In this paper, in the direction path on the signal propagation should be considered. And the edge model is used to correct the propagation of the signal. When the path is too long, it can be made for the basic obstacle here. Shorter propagation paths are studied in this section. When the path is too long to ignore the curvature of the earth, additional losses must be calculated. The following data apply to situations where the wave wavelength is much smaller than the size of the obstacle, i.e., in the VHF band or shorter wavelength (\(f > 30 \text{ MHz}\)).

2.2. Diffraction Correction of Irregular Ground Obstacles. There may be one or several separate obstacles along the propagation path. In this scenario, the shape of the obstacle should be idealized, assuming it to be a blade with negligible thickness or a thick obstacle with smooth surface and ideal curvature at the top. The shape of the real obstacle is of course more complex, and some approximate treatment can be made for the basic obstacle here. Shorter propagation paths are studied in this section. When the path is too long to ignore the curvature of the earth, additional losses must be calculated. The following data apply to situations where the wave wavelength is much smaller than the size of the obstacle, i.e., in the VHF band or shorter wavelength (\(f > 30 \text{ MHz}\)).

2.3. Single Edge Barrier. In a mountainous environment, there will be one or more separate obstacles on many propagation paths of electromagnetic signals. When calculating the field strength, the influence of obstacles in the propagation path on the signal propagation should be considered. In this paper, in diffraction correction, the case that there is a single obstacle in the direction of signal propagation is preliminarily considered and approximates to an ideal edge, and the edge model is used to correct the propagation of electromagnetic field intensity in mountainous areas.

According to the basic theoretical formula of diffraction, the signal field strength loss caused by a single edge obstacle is expressed as

\[
J(v) = 6.9 + 20 \log \left( \sqrt{(v - 0.1)^2 + 1 + v - 0.1} \right),
\]

where \(v\) represents the basic parameter of the edge obstacle, which can be expressed as

\[
v = \frac{2h}{\lambda} \sqrt{\frac{1}{d_1^2} + \frac{1}{d_3^2}},
\]

where \(\lambda\) represents the signal wavelength, \(d_1, d_3\) represent the distance from the obstacle to the transmitter and receiver, respectively, and \(h\) represents the height of the obstacle between the transmitter and receiver.

Ideally, all geometric parameters of an obstacle can be unified by a single dimensionless parameter:

\[
v = \frac{2h\theta}{\lambda} \sqrt{(1/d_1) + (1/d_3)},
\]

In the formula, \(\theta\) represents the part above the connecting line at the top of the obstacles at both ends of the connecting path. If it is below that line, then \(\theta\) is negative. \(d\) represents the path length, and \(d_1\) and \(d_3\) represent the distance from both ends of the path to the obstacle. The diffraction angle (radian) of \(\alpha\) is the same plus-minus as that of \(h\). \(\alpha\) should be less than 0.2 radian, or 12°. \(\alpha_1\) and \(\alpha_2\) denote the angle between a line of vertex and path and the path connection. The symbols of \(\alpha_1\) and \(\alpha_2\) are the same as those of \(h\), \(d, d_1, d_3\) found in Equations (10) to (13) should have a coordinated size with \(\lambda\).

Loss (dB) is caused by the presence of obstacles in the function of \(v\). When \(v\) is greater than -0.7, the approximation of the expression can be expressed as follows:

\[
J(v) = 6.9 + 20 \log \left( \sqrt{(v - 0.1)^2 + 1 + v - 0.1} \right).
\]

2.4. Screen Barrier with Limited Thickness. Interference with a receiving station (or a small earth station) can also be imagined as an obstacle with a limited thickness across the propagation path, and its effect can be imagined as three edges, namely, the vertex and both ends of the obstacle. The interference caused by these three obstacles will cause rapid fading and fluctuation of the field strength at an integral multiple distance from the wavelength. In the following simplified model, the average and minimum diffraction loss estimation methods are given according to the location. Firstly, the minimum attenuation of a single edge is considered, and then, the average loss is obtained by comprehensive evaluation. This model comes from the consistent

\[
J(v) = \frac{2h\theta}{\lambda} \sqrt{(1/d_1) + (1/d_3)}.
\]
diffraction theory (UTD) and has passed the high-precision measurement test.

(Step 1) The geometric parameters (vertex, left, and right ends) of each edge are calculated as formula (10) and (13).

(Step 2) Equation (14) is used to calculate the loss factor $j(v) = 10^{j(v)/20}$ of each edge.

(Step 3) The minimum diffraction loss $J_{min}$ is calculated as follows:

$$J_{min}(v) = -20 \log \left[ \frac{1}{J_1(v)} + \frac{1}{J_2(v)} + \frac{1}{J_3(v)} \right].$$  \hspace{1cm} (15)

Or calculate the average value according to the following:

(Step 4) The following is the calculation of the average diffraction loss:

$$J_{av}(v) = -10 \log \left[ \frac{1}{J_1(v)} + \frac{1}{J_2(v)} + \frac{1}{J_3(v)} \right].$$  \hspace{1cm} (16)

2.5. A Single Cylindrical Obstacle. Set the radius of the cylinder as $R$, note that the measured height at the highest point of the obstacle is $h$ and the distance is $d_1$ and $d_2$, and then, the diffraction loss is

$$A = J(v) + T(m, n),$$

where $J(v)$ is the Fresnel-Kirchhoff loss with the barrier vertex as the edge vertex. The dimensionless parameters can be calculated by Equations (10) to (13). For example, Equation (10) can be written as

$$v = 0.0316h \left[ \frac{2(d_1 + d_2)}{Ad_1d_2} \right]^{1/2},$$

where $h$ and $v$ are in meters, and $d_1$ and $d_2$ are in kilometers. $J(v)$ is calculated by Equation (14). $v$ is positive in the obstacles in the line-of-sight propagation, which can be calculated by Equation (14). $T(m, n)$ is the additional attenuation caused by the curvature of the obstacle:

$$T(m, n) = km^p,$$

where

$$k = 8.2 + 12.0n,$$

$$b = 0.73 + 0.27[1 - \exp(-1.43n)],$$

$$m = R \left[ \frac{(d_1 + d_2)/d_1d_2}{\pi R/\lambda} \right]^{1/3},$$

$$n = h \left[ \frac{\pi R/\lambda}{R} \right]^{2/3}.$$  \hspace{1cm} (20)

The dimensions of $R$, $d_1$, $d_2$, $h$, and $k$ should be coordinated. $T(m, n)$ has the following properties: $m$ and $T(m, n)$ tend to 0 as $R$ approaches 0. Therefore, in Equation (18), the cylinder with radius 0 is regarded as edge diffraction. Cylindrical models can be used extensively for ground modeling, but they are not applicable when there are paths across the water beyond the horizon, or very flat ground paths.

For two independent obstacles, the diffraction theory of a single edge can be used continuously to regard the top of the first obstacle as the source of the second obstacle. The geometric parameters of the first diffraction path are distances $a$ and $b$ and height $h_1$, and its loss is $L_1$ (dB). The geometric parameters of the first diffraction path are distances $b$ and $c$ and height $h_2'$, and its loss is $L_2$ (dB). $L_1$ and $L_2$ are obtained by a fixed formula. The correction term $L_c$ (dB) corresponds to the spacing $b$ of the two edges. $L_c$ is calculated as follows:

$$L_c = 10 \log \left[ \frac{(a + b)(b + c)}{b(a + b + c)} \right].$$  \hspace{1cm} (21)

When both $L_1$ and $L_2$ are greater than 15 dB, the final loss is

$$L = L_1 + L_2 + L_c.$$  \hspace{1cm} (22)

When the loss of two edges is similar, the above equation is more accurate. If a blade plays a major role, then, the geometric parameters of the first path are distances $a$ and $b + c$ and height $h_1$, and the geometric parameters of the second path are distances $b$ and $c$ and height $h_2'$.

At this point, the single edge diffraction theory can be applied to two obstacles one by one. First, $h/r$ is used to determine which is the main peak $M$, where $h$ is the height of the apex of the edge and $r$ is the radius of the first Fresnel ellipsoid, as shown in Equation (2). The loss of subpath $MR$ is obtained by $h_1'$, and then, the $T_c$ (dB) term is subtracted, that is, the part between two edges. The calculation of $T_c$ (dB) is as follows:

$$T_c = \left[ 12 - 20 \log_{10} \left( \frac{2}{1 - (a/\pi)} \right) \right] \left( \frac{q}{p} \right)^{2p},$$

where

$$p = \left[ \frac{2 (a + b + c)}{\lambda (b + c)a} \right]^{1/2} h_1,$$

$$q = \left[ \frac{2 (a + b + c)}{\lambda (a + b)c} \right]^{1/2} h_2,$$

$$\tan \left[ \frac{b(a + b + c)}{ac} \right]^{1/2}.$$  \hspace{1cm} (24)

The total loss is as follows:

$$L = L_1 + L_2 - T_c.$$  \hspace{1cm} (25)
The same method is also applicable to other cylinders. When the obstacle is a flat top structure, it is not enough to simulate it with a single blade, and the phase sum of two parts needs to be calculated: one is the diffraction of the double edges, and the other is the reflection of the roof. When the reflection coefficient of the roof or the height difference between the roof and the side wall is not known, if the reflection part is ignored, the diffraction prediction value made by the double-edge model is very accurate.

2.6. General Approaches for One or More Obstacles. The following methods are applied to cases where there is one or more obstacles on the irregular path of line-of-sight propagation (including land and sea paths and line-of-sight or cross-horizon paths). The topographic profile of the radio propagation path is divided into a number of equidistant elevations, in which the elevations of the transmitter and receiver are the first and the last points, respectively, and the other points are some distance away from them. The height and distance of each point are recorded in the profile file.

In view of the different paths profiles, the maximum parameter \( v \) should be obtained first.

Each point between point \( a \) and point \( b \) \((a < b)\) is recorded. When there is no intermediate point \( a + 1 = b \), the diffraction loss of the path is 0. Otherwise, \( v_p \) \((a < n < b)\) is calculated one by one in order to select the maximum point of \( v \):

\[
v_n = h \sqrt{\frac{2d_{an}d_{ab}}{\lambda d_{an}d_{ab}}}.
\]

In the formula,

\[
h = h_n + \frac{[d_{an}d_{ab}]}{2r_e} - \frac{[h_n d_{an} + h_x d_{an}]}{d_{ab}}.
\]

\( D_{an}, d_{ab}, \) and \( d_{an} \) are horizontal distances; \( h_n, h_p, \) and \( h_x \) are vertical heights; \( \lambda \) is wavelength; and \( r_e \) is effective earth radius. All \( h, d, r_e, \) and \( \lambda \) should be consistent.

The diffraction loss of the edge is obtained by Equation (14) when \( J(v) \) is at \( v > -0.78 \); otherwise, the value is 0. Equation (26) is calculated directly from Equation (10). The second term of Equation (27), which represents a particular geometry, gives a good approximation of the curvature of the earth at the \( n^{th} \) point.

First, the above steps are used on the entire path from the transmitter to the receiver. The main edge is the point \( P \) with the maximum \( v_p \), and its loss is \( J(v_p) \). The above steps are used twice at \( v_p > -0.78 \); \( v_1 \) and \( J(v_1) \) are calculated from the transmitter to the main edge peak; \( v_r \) and \( J(v_r) \) are calculated from the main edge peak to the receiver. Other losses on this path are as follows:

When \( v_p > -0.78 \),
\[
L = J(v_p) + T[J(v_1) + J(v_r) + C],
\]
where \( C \) represents the empirical correction coefficient
\[
C = 10.0 + 0.04D.
\]

When \( v_p < -0.78 \),
\[
L = 0,
\]

where \( D \) represents the full length of the path (km), and
\[
T = 1.0 - \exp\left[-\frac{J(v_p)}{6.0}\right].
\]

In the Deygout method, the path across the horizon includes at most 3 edges, among which, when the diffraction loss of the main peak is greater than 0, two secondary edges are still needed. When different effective earth radii are used for prediction on the same path profile, in order to avoid the problem of discontinuity caused by falling into the cycle of finding the point, the average effective earth radii of the main edge peaks and the auxiliary edge peaks on both sides can be obtained first, and then, the diffraction loss can be predicted with different effective earth radii.

2.7. Wedge-Shaped Obstruction with Finite Conduction. The following method is used to predict the diffraction loss of a wedge-shaped material with finite conduction, applicable to the diffraction loss caused by building angles and roof ridges or the wedge-shaped ridge topography. The requirement of this method is to obtain the conductivity and relative dielectric constant of the obstacle and to assume that there is no current transmission on the wedge surface. The method is based on the Unified Diffraction Theory (UTD), which also takes into account the diffraction of the shadow region and the line-of-sight region and the smooth transition of the predicted values between the two regions. The electric field value of the UTD formula at the field point is as follows:

\[
e_{UTD} = e_0 \frac{\exp(-jk s_1)}{s_1} D^\perp \sqrt{\frac{s_1}{s_2 + s_2}} \cdot \exp(-jk s_2),
\]

where \( e_0 \) represents the relative source amplitude, \( e_{UTD} \) represents the electric field value of the field point, \( k \) represents the number of waves, \( 2\pi/\lambda \), \( s_1 \) represents the distance between the source point and the diffraction edge, \( s_2 \) represents the distance between the field point of the diffraction edge, \( D^\perp \) represents the diffraction factor, depending on the incident angle of the diffraction edge (parallel or perpendicular to the incident axis), and the dimensions of \( s_1, s_2 \), and \( \lambda \) should be consistent. The diffraction factors of finitely...
conducting wedges are as follows:

\[
D\| = -\frac{\exp(-jn/4)}{2n\sqrt{2\pi k}} \left\{ \cot \left( \frac{\pi + (\Phi_2 - \Phi_1)}{2n} \right) - \frac{F(kLa^*(\Phi_2 - \Phi_1)) + \cot \left( \frac{\pi - (\Phi_2 - \Phi_1)}{2n} \right) \cdot F(kLa^*(\Phi_2) - \Phi_1))}{\Phi_2 - \Phi_1} \right\}.
\]

(32)

In the formula, \(\Phi_1\) denotes the incident angle measured from the incident surface (0 surface), \(\Phi_2\) denotes the diffraction angle measured from the incident surface (0 surface), \(n\) denotes the external wedge angle, which needs to be multiplied by \(\pi\) (actual value = \(n\pi\) (rad)), \(j = \sqrt{-1}\), and \(F(x)\) is the Fresnel integral:

\[
F(x) = 2j\sqrt{x} \cdot \exp(jx) \cdot \int_{\sqrt{x}}^{\infty} \exp(-jt^2)dt, \quad (33)
\]

\[
\int_{\sqrt{x}}^{\infty} \exp(-jt^2)dt = \sqrt{\frac{\pi}{8}} (1 - j) - \int_{0}^{\sqrt{x}} \exp(-jt^2) dt. \quad (34)
\]

This integral can be computed by numerical integration. The above equation can be approximated as

\[
\int_{\sqrt{x}}^{\infty} \exp(-jt^2)dt = \sqrt{\frac{\pi}{2}} A(x), \quad (35)
\]

where

\[
A(x) = \begin{cases} 
\frac{1 - j}{2} - \exp(-jx) \left\{ \sum_{n=0}^{11} \frac{1}{4} (a_n + jb_n) \left( \frac{x}{4} \right)^n \right\}, & \text{if } x < 4 \\
-\exp(-jx) \left\{ \sum_{n=0}^{11} \frac{1}{4} (c_n + jd_n) \left( \frac{x}{4} \right)^n \right\}, & \text{otherwise.}
\end{cases} \quad (36)
\]

\(R_0^|\), \(R_n^|\) are the reflection coefficients at vertical or paral-
the reflection coefficient is 0, the result of this formula is the same as that of the edge diffraction.

2.8. Correction Steps of Electromagnetic Field Intensity Prediction Diffraction. The following method is used to predict the diffraction loss of a wedge-shaped material with finite.

In accordance with the basic processing flow of the electromagnetic signal propagation model as shown in Figure 1, the main steps of predicting the field intensity distribution with the 1546 model include:

(Step 1) Initialize and set the environment model.
(Step 2) Initialize and return parameter state.
(Step 3) Calculate the basic propagation and path losses.
(Step 4) Look up the table.
(Step 5) Return the table lookup value.
(Step 6) Call the environment model base.
(Step 7) Return environmental data.
(Step 8) Correct.
(Step 9) Correct mixed path/time probability/frequency.
(Step 10) Correct the height and field strength of the transmitting and receiving antennas.
(Step 11) Correct clearance angle/location probability/Emax detection.
(Step 12) Return the corrected value.
(Step 13) Calculate propagation and path losses: synthesize table lookup value and attenuation value.
(Step 14) Return the basic propagation and path losses.

3. Results and Discussion

3.1. Subheadings. In order to verify and evaluate the performance of the electromagnetic field strength prediction method based on the ITU-R P.1546 model, a method is designed in this paper to evaluate the performance of the method in the field strength prediction by comparing the simulation prediction with the measured data. The 1546 model, which does not take the diffraction effect correction into account, is also calculated and compared in the simulation prediction. The main difficulty of the simulation prediction is how to extract the corresponding parameters based on more detailed terrain, ground objects, and other data to correct the propagation model. However, the difficulty of the measured data acquisition lies in the uncontrollable factors in the electromagnetic environment, among which the
most important ones are the uncontrollable external disturbance and self-disturbance.

In this paper, the determination coefficient, root mean square error, and average error are used to measure the accuracy, as follows.

\[
R^2 = \frac{\text{COV}^2(E_{\text{pre}}, E_{\text{rea}})}{\text{Var}(E_{\text{pre}}) \text{Var}(E_{\text{rea}})}.
\]  

In the formula, \(E_{\text{pre}}\) is the predicted result of field intensity output by the model, and \(E_{\text{rea}}\) is the measured result of field intensity.

\[
\sigma_E = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (E_{\text{pre},i} - E_{\text{rea},i})^2}.
\]

In the formula, \(\sigma_E\) is the root mean square error of the predicted field strength relative to the measured value.

\[
\text{err} = \frac{1}{N} \sum_{i=1}^{N} |E_{\text{pre},i} - E_{\text{rea},i}|.
\]  

err is the mean absolute error between the predicted and measured field strength values.

The field intensity observation experiment was conducted in two different mountainous areas by means of ultrashort wave radio, matching antenna, and power supply equipment. In addition, a mobile vehicle equipped with receiving antenna and other related equipment was used to collect and measure the field intensity corresponding to the electromagnetic signals at multiple points. Combined with the physical geography of the mountains and the basic parameters of experimental equipment, the field intensity

| Longitude  | Latitude  | Height | Measured field strength | Modified model Prediction results | Uncorrected modified model Prediction results | ICS software Prediction results |
|-----------|-----------|--------|-------------------------|-----------------------------------|---------------------------------------------|-------------------------------|
| 117.47044 | 36.42849  | 495    | 22.784                  | 28.0166                           | 18.2799                                     | 18.5234                       |
| 117.47044 | 36.428488 | 495    | 38.7592                 | 43.0306                           | 18.28                                        | 18.7358                       |
| 117.47013 | 36.427628 | 495    | 25.8452                 | 26.4031                           | 18.5257                                     | 16.1948                       |
| 117.47012 | 36.427626 | 495    | 36.0796                 | 36.7268                           | 18.5258                                     | 20.2752                       |
| 117.46981 | 36.426766 | 495    | 31.3682                 | 28.5766                           | 18.5927                                     | 17.5079                       |
| 117.46981 | 36.426763 | 495    | 19.3239                 | 19.754                            | 18.5928                                     | 19.0938                       |
| 117.4695  | 36.425903 | 495    | 25.0864                 | 30.373                            | 18.6013                                     | 17.1426                       |
| 117.4695  | 36.425901 | 495    | 35.7749                 | 36.082                            | 18.6014                                     | 20.2773                       |
| 117.46919 | 36.425041 | 414    | 33.4743                 | 34.322                            | 18.6591                                     | 18.8263                       |
| 117.46919 | 36.425038 | 414    | 35.6233                 | 36.3091                           | 18.6593                                     | 19.7894                       |
| 117.46888 | 36.424178 | 414    | 26.7722                 | 32.428                            | 18.6676                                     | 20.3606                       |
| 117.46888 | 36.424176 | 414    | 35.708                  | 39.1348                           | 18.6677                                     | 17.2056                       |
| 117.46856 | 36.423316 | 414    | 28.7753                 | 31.3567                           | 18.7319                                     | 19.846                        |
| 117.46856 | 36.423313 | 414    | 34.6269                 | 37.1839                           | 18.732                                      | 18.1015                       |
| 117.46825 | 36.422453 | 414    | 33.7977                 | 32.8018                           | 18.7933                                     | 18.7942                       |
| 117.46825 | 36.422451 | 414    | 35.6533                 | 37.9868                           | 18.7934                                     | 18.0807                       |
| 117.46794 | 36.421591 | 414    | 33.5383                 | 34.6322                           | 18.8039                                     | 20.0508                       |
| 117.46794 | 36.421589 | 414    | 26.8122                 | 31.555                            | 18.804                                      | 20.563                        |
| 117.46763 | 36.420729 | 414    | 23.6421                 | 28.0866                           | 18.8621                                     | 17.7462                       |
| 117.46763 | 36.420726 | 414    | 39.1774                 | 39.783                            | 18.8623                                     | 20.0933                       |
| 117.46731 | 36.419866 | 414    | 61.04                   | 38.9964                           | 18.8726                                     | 18.4299                       |
| 117.46731 | 36.419864 | 414    | 69.04                   | 39.6481                           | 18.8728                                     | 18.3112                       |
| 117.467   | 36.419002 | 414    | 62.04                   | 26.7161                           | 18.9524                                     | 20.5299                       |
| 117.467   | 36.419    | 414    | 57.04                   | 22.6321                           | 18.9526                                     | 17.7656                       |
| 117.46723 | 36.418124 | 314    | 68.04                   | 37.9287                           | 19.0185                                     | 20.2808                       |
| 117.46723 | 36.418121 | 314    | 72.04                   | 40.2566                           | 19.0187                                     | 20.9546                       |
| 117.46747 | 36.417246 | 314    | 60.04                   | 35.0796                           | 19.0667                                     | 20.7386                       |
| 117.46747 | 36.417243 | 314    | 64.04                   | 25.0355                           | 19.0669                                     | 16.0675                       |
| 117.4677  | 36.416367 | 314    | 96.04                   | 37.1593                           | 19.1332                                     | 19.3316                       |
| 117.4677  | 36.416364 | 314    | 69.04                   | 23.4115                           | 19.1334                                     | 17.496                        |
| 117.46793 | 36.415489 | 314    | 56.04                   | 39.5785                           | 19.1998                                     | 19.8891                       |
The distribution of ultrashort wave radio in this region was simulated and calculated.

3.2. Results in Area A. The modified model, original model, and ICS software are used in area A to predict the field strength and compared with the actual measured value. The typical measurement results in areas with large height fluctuations are shown in Table 1. The comparison between the original model and the modified model is shown in Figure 2(a), and the comparison between the

**Figure 2:** (a) Predicted field strength by the original model and the modified model in area A. (b) Predicted field strength and measured field strength distribution in area A.
modified model and the ICS software is shown in Figure 2(b).

As shown in Table 1, the height of this sampled data group fluctuates greatly, and the height fluctuates nearly 200 meters. It can be clearly seen from Figure 2(a) that compared with the original ITU-R P.1546 model, the field strength prediction results based on the revised ITU-R P.1546 model are in good agreement with the measured field strength data. According to formulas (42) and (44), the determination coefficient of the modified model is 0.845, the root mean square error is 5.931 dB\(\mu\)V/m, and the average absolute error is 2.603 dB\(\mu\)V/m, while the determination coefficient of the original model is 0.006.

It can be seen from Figure 2(b) that compared with the calculation results of the ICS software, the field strength prediction results based on the revised ITU-R P.1546 model are closer to the actual measured results in terms of value and trend. The determination coefficient of the results of the ICS software is 0.169, so it can be seen from the statistical analysis results that the modified model has a much higher coefficient of determination, indicating that compared with the original model and ICS software, the modified ITU-R P.1546 model can adapt to this mountainous area with obvious topography.

What is more, a total of 3884 sets of data tested in mountain area A are statistically analyzed. The determination coefficient of the modified model is 0.976, the root mean square error is 16.927 dB\(\mu\)V/m, and the average absolute error is 2.527 dB\(\mu\)V/m.

According to the discussion above, compared with the original model and ICS software, the modified ITU-R

| Longitude | Latitude | Height | Measured field strength | Modified model Prediction results | Uncorrected modified Model prediction results | ICS software Prediction results |
|-----------|----------|--------|-------------------------|-----------------------------------|---------------------------------------------|-------------------------------|
| 117.708   | 35.8517  | 178    | 46.236                  | 45.8832                           | 29.5958                                     | 30.8491                       |
| 117.708   | 35.8517  | 178    | 47.098                  | 46.75                             | 29.5956                                     | 28.1712                       |
| 117.7085  | 35.85437 | 178    | 43.7944                 | 42.7128                           | 29.4799                                     | 29.3088                       |
| 117.7085  | 35.85437 | 178    | 48.1022                 | 52.1082                           | 29.4797                                     | 29.6885                       |
| 117.709   | 35.85357 | 178    | 45.3714                 | 46.9492                           | 29.3958                                     | 30.1577                       |
| 117.709   | 35.85357 | 178    | 43.8045                 | 46.0795                           | 29.3956                                     | 28.5521                       |
| 117.7095  | 35.85277 | 178    | 47.5033                 | 51.2638                           | 29.3158                                     | 31.2398                       |
| 117.7095  | 35.85276 | 178    | 36.5418                 | 38.1916                           | 29.3156                                     | 27.1532                       |
| 117.71    | 35.85196 | 185    | 39.4194                 | 45.1655                           | 29.2375                                     | 26.6682                       |
| 117.71    | 35.85196 | 185    | 34.8515                 | 34.2715                           | 29.2373                                     | 26.866                       |
| 117.71    | 35.8519  | 185    | 38.4794                 | 40.3106                           | 29.2312                                     | 29.6204                       |
| 117.71    | 35.8519  | 185    | 32.3551                 | 33.0539                           | 29.2312                                     | 29.2735                       |
| 117.7108  | 35.85126 | 185    | 43.3582                 | 44.7876                           | 29.1548                                     | 27.1326                       |
| 117.7108  | 35.85126 | 185    | 35.8553                 | 37.4266                           | 29.1548                                     | 29.4299                       |
| 117.7116  | 35.85062 | 185    | 43.8938                 | 48.3461                           | 29.0734                                     | 27.6986                       |
| 117.7116  | 35.85062 | 185    | 30.7923                 | 29.8799                           | 29.0733                                     | 26.498                       |
| 117.7123  | 35.84998 | 179    | 29.239                  | 33.4362                           | 18.2181                                     | 15.3102                       |
| 117.7123  | 35.84998 | 179    | 28.8912                 | 26.3211                           | 18.2181                                     | 16.6991                       |
| 117.7131  | 35.84935 | 179    | 38.5259                 | 38.369                            | 23.8795                                     | 25.4416                       |
| 117.7131  | 35.84934 | 179    | 41.3282                 | 46.9653                           | 23.8794                                     | 23.8747                       |
| 117.7139  | 35.84871 | 179    | 39.436                  | 43.0395                           | 28.8348                                     | 28.6936                       |
| 117.7139  | 35.84871 | 179    | 46.3841                 | 44.1824                           | 28.8347                                     | 26.9046                       |
| 117.7147  | 35.84807 | 179    | 33.2248                 | 33.6186                           | 28.7607                                     | 28.1243                       |
| 117.7147  | 35.84807 | 179    | 40.3965                 | 42.7377                           | 28.7607                                     | 26.6967                       |
| 117.7155  | 35.84743 | 179    | 49.6388                 | 47.1077                           | 28.6856                                     | 29.1129                       |
| 117.7155  | 35.84743 | 179    | 48.7131                 | 50.1768                           | 28.6855                                     | 26.2339                       |
| 117.7162  | 35.84679 | 179    | 42.3141                 | 43.5969                           | 28.5897                                     | 27.1897                       |
| 117.7162  | 35.84679 | 179    | 48.9966                 | 47.8809                           | 28.5896                                     | 28.7789                       |
| 117.717   | 35.84615 | 179    | 36.9246                 | 40.7389                           | 28.4993                                     | 26.0008                       |
| 117.717   | 35.84615 | 179    | 46.9615                 | 45.2969                           | 28.4992                                     | 30.259                       |
| 117.7178  | 35.84551 | 179    | 41.72                   | 43.0521                           | 28.4169                                     | 29.1489                       |
| 117.7178  | 35.84551 | 179    | 40.0697                 | 44.1006                           | 28.4168                                     | 27.5862                       |
| 117.7186  | 35.84487 | 186    | 36.3089                 | 34.9426                           | 28.3361                                     | 28.1167                       |
| 117.7186  | 35.84487 | 186    | 46.1627                 | 43.2275                           | 28.336                                      | 28.318                       |
P.1546 model is very relevant in mountain area A with obvious undulations, which can adapt to the mountain area, improve the prediction accuracy, and make better predictions.

3.3. Results in Area B. The same test was carried out in area B. The typical results in areas with less height fluctuations are shown in Table 2. The comparison between the original model and the revised model is shown in Figure 3(a), and
the comparison between the revised model and the ICS software is shown in Figure 3(b).

As shown in Table 2, it can be seen that the height fluctuation of this sampling data group is small and the maximum height difference is only 8 meters. It can be clearly seen from Figure 3(a) that compared with the original ITU-R P.1546 model, the field strength prediction results based on the revised ITU-R P.1546 model have a high consistency with the measured field strength data. The statistical analysis shows that the determination coefficient of the modified model is 0.848, the root mean square error is 6.026 dB/μV/m, and the average absolute error is 2.203 dB/μV/m.

Compared with Figure 2(b), it can be seen from Figure 3(b) that in this region with small height fluctuations, the field strength prediction of the ICS software has similar trends to the actual measured results, but there is still a big gap between the prediction and the actual results. The field strength prediction results based on the revised ITU-R P.1546 model are closer to the actual measurement results in terms of trends and values.

What’s more, a total of 3980 sets of test data in mountain area B are statistically analyzed. The determination coefficient of the modified model is 0.978, the root mean square error is 15.365 dB/μV/m, and the average absolute error is 1.992 dB/μV/m.

According to the discussion above, in areas with relatively mild fluctuations, the trends of various prediction methods are closer to the actual measured values, but the prediction results of the modified model are still significantly better than those of other prediction methods, indicating that the modified ITU-R P.1546 model is better than other models and can predict the field strength distribution in mountainous areas better.

4. Conclusions

Electromagnetic propagation simulation is the basis of various electromagnetic equipment simulation and electromagnetic analysis and calculation, which directly determines the fidelity, timeliness, and usability of various simulation calculations. In this paper, the ITU-R P.1546 model, launched by ITU, is introduced to calculate the propagation distribution of electromagnetic waves under complex terrain and complex meteorological conditions. In this paper, the model algorithm and the calculation process of electromagnetic signal field intensity were firstly analyzed, and the verification experiment was conducted in the mountainous environment. On the basis of more accurate scene information such as actual terrain and taking into account the influencing factors such as actual terrain to correct the relevant parameters in the model, the test results in the mountainous areas of A and B prove that the method of modifying the ITU-R P.1546 model for field strength prediction by considering the diffraction factors in the mountainous environment is effective and further improves the traditional ITU-R P.1546 model’s field strength prediction accuracy.

The focus of this paper is only on the case of a single obstacle, but there are many peaks in the actual mountain environment. Therefore, in a future work, it is necessary to give full consideration to how to further improve the field strength prediction algorithm based on the ITU-R P.1546 model under the condition of approximately random distribution of obstacles.

Data Availability

The (area A and area B) data used to support the findings of this study were supplied by Jialuan He under license and so cannot be made freely available. Requests for access to these data should be made to Jialuan He, Beijing Aerospace Chenxin Technology Co., Ltd., Beijing, 102308, China (hejialuan@163.com).

Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

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