Field Measurement and Simulation of Electromagnetic Radiation of Communication Base Station in Urban Area

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Abstract. The X3D propagation model and ray-tracing algorithm were used to system modeling and simulation for the ambient electromagnetic environment of communication base station near Beijing Municipal Institute of Labor Protection. The simulation results were in agreement with the field measurement results through comparative analysis, which verified that the propagation model and algorithm are scientific, practical, and effective. The propagation model and algorithm can effectively overcome the limitations that empirical model cannot adapt to the complex building model in different urban, and other deterministic model cannot accurately find the propagation path.

Introduction

With the advances in communication technology and improvements in people living standard, the telecommunication industry has been developing rapidly. In order to ensure the maximum communication quality and data transfer speed in densely populated areas, telecommunication operators have continuously installed communication base stations in urban area. Some of these base stations are set on rooftops of residential buildings, which have resulted in increasingly higher levels of electromagnetic radiation in the environment [1]. Many residents have concerned that the ambient electromagnetic radiation of communication base stations would affect the human health [2,3]. Therefore, a systematic investigation into the issue is very important. At present, the electromagnetic radiation research for communication base stations mainly focuses on the impact of electromagnetic radiation of communication base stations on the surrounding environments [4,5], electromagnetic radiation distribution of base stations [6,7], and algorithms of base stations [8,9]. However, the contrast research of field measurement and simulation of electromagnetic radiation for communication base station in urban is rare.

Based on the uniform theory of diffraction (UTD), we adopted the X3D propagation model and ray-tracing algorithm to model and simulate the ambient electromagnetic environment of communication base station near Beijing Municipal Institute of Labor Protection, and studied the vertical distribution of electromagnetic radiation field of base station. Through comparative analysis of field measurement results and simulation results, we proved the practicality and effectiveness of the model and algorithm. Studies on the effects of electromagnetic radiation of base stations on the surrounding environments play a positive role in alleviating public fear, and play an important guiding role in base station construction.
Measurement Conditions

Fig. 1 shows the ambient environment of communication base station near Beijing Municipal Institute of Labor Protection. The communication base station is set on the rooftop of the Kyoto Ruicheng building. Table 1 shows the technical parameters of base station. When the base station is shaded by tall buildings in the direction of the antenna radiation main lobe, the measurement points should be set on different building floors in order to measure the vertically electromagnetic field distribution. Therefore, in this paper, the measurement points was set on the second, third, fourth, fifth, sixth, and ninth floor of Beijing Municipal Institute of Labor Protection, which corresponded to the heights of 7.3 m, 10.8 m, 14.3 m, 17.8 m, 21.3 m, and 31.8 m respectively.

The electric field intensity was measured using the Narda SRM 3000 electromagnetic radiation analyzer with a frequency range of 75MHz–3GHz. The relative positions between the transmitter and receivers were measured by using the DISTO D3 laser rangefinder.

![Figure 1. Ambient environment of communication base station near Beijing Municipal Institute of Labor Protection.](image)

Table 1. Technical parameters of base station.

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Power (W)</th>
<th>Gain (dBi)</th>
<th>Height (m)</th>
<th>Angle of Tilt (°)</th>
<th>Vertical Half-power Beam width(°)</th>
<th>Standing Wave Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1805~1860</td>
<td>20</td>
<td>9</td>
<td>27</td>
<td>19</td>
<td>19</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Simulation Model

Simulation Conditions. During the simulation process, in order to close to the real situation and enable the simulation results to coincide to the field measurement results, the specific parameters were set as follows. Considering the influence of material properties on the propagation characteristics, The type of building materials was set the reinforced concrete with the thickness of 300 mm, conductivity of $1.5 \times 10^{-2} \, (\Omega \cdot \text{m})^{-1}$, and permittivity of 15. Since the strongest signal channel was chosen as the simulation channel, the waveform type was set the sine wave with the carrier frequency of 1833MHz, and the band width of 1MHz. The properties of receiving and transmitting antennas are shown in Table 2. The transmitter was set to the point type, transmitter height was 27m with the angle of tilt 19° and input power of 43dBm. The receiver was set the route type with intervals of 3.5m, therefore, the receiver heights were 7.3m, 10.8m, 14.3m, 17.8m, 21.3m, and 31.8m respectively. The propagation model was set to the X3D with the ray spacing of 0.25, the reflection number of 6, the transmission number of 4, and the diffraction number of 1.
Table 2. Properties of receiving and transmitting antennas.

<table>
<thead>
<tr>
<th>Antenna Name</th>
<th>Antenna Type</th>
<th>Gain (dBi)</th>
<th>Polarization Mode</th>
<th>Vertical Half-power Beam width(°)</th>
<th>Standing Wave Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitting Antenna</td>
<td>Omnidirectional</td>
<td>9</td>
<td>Vertical</td>
<td>19</td>
<td>1.4</td>
</tr>
<tr>
<td>Receiving Antenna</td>
<td>Omnidirectional</td>
<td>1</td>
<td>Vertical</td>
<td>90</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The simulation scene (Fig. 2) was established referring to the practical environment (see red dotted line area in Fig. 1). To simplify the calculation, the cube model was primarily adopted. The communication base station is set in urban, the environment contains other diffusers such as trees, cars and pedestrians in addition to the main buildings, here, we ignored the minor impact of these diffusers on the radiation field intensity.

![Figure 2. Simulation scene.](image)

Theoretical Prediction Formula.

Received Power. The received power is defined as:

\[
P_R = P_T - L_T + G_T - L_{Path} + G_R - L_R\]

(1)

where \(P_T\) and \(P_R\) are the powers of transmitter and receiver (dBm); \(G_T\) and \(G_R\) are the gains of transmitting and receiving antenna (dBi); \(L_T\) is the feeder loss between the transmitter and transmitting antenna (dB); \(L_{Path}\) is the transmission path loss (dB); and \(L_R\) is the feeder loss (dB) between the receiver and receiving antenna.

Path Loss. The path loss is obtained from the equation (1):

\[
L_{Path} = P_T - P_R + G_T - L_T + G_R - L_R
\]

(2)

Results and Discussion

Since the base station was shaded by tall buildings in the direction of the antenna radiation main lobe, the measurement points was set on the second, third, fourth, fifth, sixth, and ninth floor of the Beijing Municipal Institute of Labor Protection, and the vertical distribution of electromagnetic radiation field for base station was studied. Table 3 shows the electric field intensity data within Beijing Municipal Institute of Labor Protection.
<table>
<thead>
<tr>
<th>Measurement Number</th>
<th>Measurement Point</th>
<th>Measurement Height H (m)</th>
<th>Electric Field Intensity $E$ (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Second Floor</td>
<td>7.3</td>
<td>0.580</td>
</tr>
<tr>
<td>2</td>
<td>Third Floor</td>
<td>10.8</td>
<td>1.196</td>
</tr>
<tr>
<td>3</td>
<td>Fourth Floor</td>
<td>14.3</td>
<td>1.532</td>
</tr>
<tr>
<td>4</td>
<td>Fifth Floor</td>
<td>17.8</td>
<td>1.838</td>
</tr>
<tr>
<td>5</td>
<td>Sixth Floor</td>
<td>21.3</td>
<td>1.530</td>
</tr>
<tr>
<td>6</td>
<td>Ninth Floor</td>
<td>31.8</td>
<td>0.297</td>
</tr>
</tbody>
</table>

The conversions between electric field intensity $E$ (V/m), power density $S$ (W/m$^2$), power $P_R$ (W) and power $P_R$ (dBm) are involved while comparing the field measurement results with the simulation results. The conversion relationships between them are shown as follows.

(1) The relationship between electric field intensity $E$ (V/m) and power density $S$ (W/m$^2$) \[10,11\]:

$$ S = \frac{E^2}{\eta_0} = \frac{E^2}{120\pi} $$ \hspace{1cm} (3)

Where $E$ is the electric field intensity (V/m); $\eta_0=120\pi$ is the free space wave impedance; and $S$ is power density (W/m$^2$).

(2) The relationship between power density $S$ (W/m$^2$) and received power $P_R$ (W) \[10,11\]:

$$ P_R = S G_R \frac{\lambda^2}{4\pi} = \frac{S G_R}{\lambda^2} \cdot \frac{c^2}{f^2} $$ \hspace{1cm} (4)

Where $S$ is the power density (W/m$^2$); $\lambda$ is the wavelength (m); $G_R$ is the receiving antenna gain (multiple); $c$ is the velocity of light (m/s); $f$ is the frequency (Hz); and $P_R$ is the received power (W).

(3) The relationship between received power $P_R$ (W) and received power $P_R$ (dBm) \[10,11\]:

$$ P_R (\text{dBm}) = 10 \log_{10} [P_R (\text{W})] + 30 (\text{dB}) $$ \hspace{1cm} (5)

According to the above conversion relationships, the electric field intensity (V/m), power density (W/m$^2$) and power (dBm) as functions of measurement height are shown in Fig.3. The similar changing trends of electric field intensity, power density and power are observed with the measurement height increasing. The maximum in electric field intensity, power density and power are clearly visible when the measurement point was set on the fifth floor of the Beijing Municipal Institute of Labor Protection, which are 1.838 V/m, $8.965\times 10^{-3}$ W/m$^2$ and -17.185 dBm respectively. This shows that the base station antenna has a certain beam width and a main radiation direction in vertical direction.
During the simulation process, in order to study the vertical distribution characteristics of electromagnetic radiation field of communication base station, the receivers were set vertically. Fig. 4(a) shows the multipath results between the transmitter and receiver when the receivers was set at heights of 7.3m, 10.8m, 14.3m, 17.8m, 21.3m, and 31.8m. Fig. 4(b) shows the multipath distribution between the transmitter and receiver. The multipath propagation of electromagnetic wave means that there are other paths to reach the receiver in addition to the direct path, which are due to the reflection, diffraction and other physical phenomena. There are 25 propagation paths from the transmitter to each receiver as shown in Fig. 4(a). There can be direct, reflective, diffractive, and other paths from the transmitter to the receiver as shown in Fig. 4(b). Since there exist many vehicles, utility poles and trees in actual complex electromagnetic environment, causing a potential increase in the number of propagation paths.

Fig. 5 (a) shows the relationship between received power and measurement height in simulation scene when the measurement heights are 7.3m, 10.8m, 14.3m, 17.8m, 21.3m and 31.8m. Fig. 5(b)
shows the received power as a function of measurement height. Fig.5(c) shows the relationship between path loss and measurement height in simulation scene when the measurement heights are 7.3m, 10.8m, 14.3m, 17.8m, 21.3m and 31.8m. Fig. 5(d) shows the path loss as a function of measurement height. We observe that the changing trends of path loss and received power is just opposite with the measurement height increasing, as shown in Fig.5. The received power firstly increases and then decreases with the measurement height increasing. When the measurement height is 17.8m, the received power reaches the maximum. However, the path loss firstly decreases and then increases with the measurement height increasing. When the measurement height is 17.8m, the path loss reaches the minimum. The reduction in path loss led directly to the increase in received power.

Fig. 6(a) shows the multipath results between the transmitter and receiver when the measurement height is 17.8m. When expanding propagation paths, we can see that there are 25 propagation paths from the transmitter to the receiver. Tx represents the transmitter, Rx represents the receiver, D represents the diffraction, and R represents the reflection. The total received power of the receiver is -17.352 dBm. The direct propagation path mainly contributes to the total received power. Path # 1 indicates that the ray reaches the receiver by a direct, and the received power is -17.51dBm. Path # 2 indicates that the ray reaches the receiver by a direct, and the received power is -34.47dBm. Fig. 6 (b) shows the multipath distribution between transmitter and receiver when the measurement height is 17.8m. The ray transmission includes the direct transmission, reflection and diffraction.
The comparison between field measurement results and simulation results is shown in Fig. 7. The simulation results are in agreement with the field measurement results through comparative analysis, which verified that the propagation model and algorithm are scientific, practical, and effective. Therefore, the propagation model and algorithm can satisfy the scientific requirements of the electromagnetic field prediction of communication base station in urban area. The certain errors between simulation results and field results may be caused by the following aspects. (1) During the three-dimensional modeling process, we ignore the building surfaces which may affect the calculation accuracy. (2) Since the building materials are complex and unevenly distributed, the prediction accuracy may be affected. (3) Ignoring the scattering objects of cars, poles and trees.

Summary
The propagation model and algorithm adopted in this paper apply to the prediction analysis of electromagnetic field of communication base station in different urban area. Firstly, the three-dimensional building models in urban area are established. Then, the technical parameters of transmitting and receiving antennas are set. Finally, each propagation ray is traced. We observe that the simulation results are in agreement with the field measurement results through the comparative analysis. It indicates that the propagation model and algorithm are scientific, practical, and effective.

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