

3D Geospatial Visualization for Antenna Deployment in Mobile Communication Systems

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Abstract In mobile communication systems, antenna characteristics are typically distributed in .msi files, which contain horizontal (H-plane) and vertical (V-plane) radiation patterns. While these two-dimensional cuts provide useful information, they cannot fully capture the 3D behavior of the antenna. This paper presents an interactive web-based tool that processes MSI files to visualize 2D radiation patterns, reconstruct 3D radiation surfaces, and analyze antenna deployment within a geospatial environment. The system computes key parameters such as distance, tilt, bearing, gain, and half-power beamwidth (HPBW), enabling real-time and intuitive exploration of antenna performance for research, network planning, and education.

Keyword Antennas, Mobile communication, Web-based tools

1. INTRODUCTION

In mobile communication systems, antennas are often deployed in array configurations, each supporting multiple frequencies and tilt settings. To describe these complex antenna characteristics, the MSI (Microwave Antenna Specification Information) format is widely used, providing horizontal and vertical radiation patterns. While these 2D patterns are essential for understanding antenna behavior, they provide only a partial view. To fully capture antenna performance, a 3D representation of the radiation pattern is required, which can be derived through mathematical modeling

Furthermore, antenna deployment is influenced by environmental and geographical parameters, such as mounting height, bearing, and electrical tilt. These factors directly affect effective gain, coverage area, and user experience. Therefore, visualization tools that combine antenna specifications with geospatial context are importance in network design and optimization.

In this paper, we present a web-based visualization tool that enables interactive exploration of antenna radiation patterns. The system allows users to upload MSI files, visualize the H- and V-plane patterns, and generate corresponding 3D radiation models through computational methods. In addition, a 3D animation environment is integrated with a digital map interface, allowing antennas to be virtually placed on buildings for analysis of gain, coverage, and 3 dB beamwidth in realistic environments. By bridging standardized antenna specifications with interactive visualization and geospatial modeling, the proposed tool provides a practical and intuitive framework for analyzing

antenna behavior in mobile communication networks.

2. ANTENNA GAIN CALCULATION

2.1. MSI FILE STRUCTURE

MSI file (Fig. 1) is an ASCII Text file and the general information; horizontal data points and vertical data points are placed in a single file. The MSI file provides essential antenna characteristics, including maximum gain, operating frequency, beamwidths, and tilt information. These values are vendor-defined and remain fixed unless modified by the user for analysis. Table I summarizes the antenna specifications used in this work.

There must be 360 data points (0 through 359) for the horizontal data and 360 data points (0 through 359) for the vertical data. The antenna gain unit is dBd. If the Gain is in dBi, it must be indicated after the Gain value (separated with at least one space). All gain datapoints are relative to maximum gain being zero. Any value below zero is assumed to be negative.

```
antenna.msi
NAME <name>
MAKE <make>
FREQUENCY <frequency>
H_WIDTH <h_width>
V_WIDTH <v_width>
FRONT_TO_BACK <front_to_back>
GAIN <gain>
TILT <tilt>
POLARIZATION <polarisation>
COMMENT <comment>
HORIZONTAL 360
0 <0H>
.
.
.
359 <359H>
VERTICAL 360
0 <0V>
.
.
.
359 <359V>
```

Fig.1 Template of an .msi file [4]

TABLE I. MSI Parameter [4]

Variable	Comment
NAME	Name of the antenna
MAKE	Name of the manufacturer
FREQUENCY	Frequency in MHz
H_WIDTH	Opening angle in the horizontal plane between the -3 dB points
V_WIDTH	Opening angle in the vertical plane between the -3 dB points
FRONT TO BACK	Front to back ratio in dB
GAIN	Antenna gain in dBd when in dBi this must be specified
TILT	Electrical tilt of the main beam in degrees
POLARIZATION	Horizontal, Vertical, +45 or -45
COMMENT	Comment
0H..359H	Horizontal gain datapoints per horizontal angle relative to maximum gain being zero. Any value below zero is assumed to be negative. Minus sign is not used with these values
0V..359V	Horizontal gain datapoints per horizontal angle relative to maximum gain being zero. Any value below zero is assumed to be negative. Minus sign is not used with these values

To analyze the antenna radiation patterns, the raw data in MSI files were first parsed using a Python function. This function reads and processes the horizontal and vertical antenna gain patterns along with the maximum gain of the antenna.

2.2. 2D RADIATION PATTERN COMPUTATION

The MSI file provides horizontal and vertical attenuation values relative to the maximum antenna gain. These values are represented as discrete data points for the horizontal pattern and the vertical pattern. To enable visualization, the system parses these attenuation values and combines them with the maximum gain specified in the MSI header.

The gain in each plane is computed as:

$$G_H(\phi) = G_{\max} - A_H(\phi), \quad (1)$$

$$G_V(\theta) = G_{\max} - A_V(\theta), \quad (2)$$

where $G_{\max}$ is the maximum antenna gain (in dBi), and $A_H(\phi)$, $A_V(\theta)$ represent the horizontal and vertical attenuations

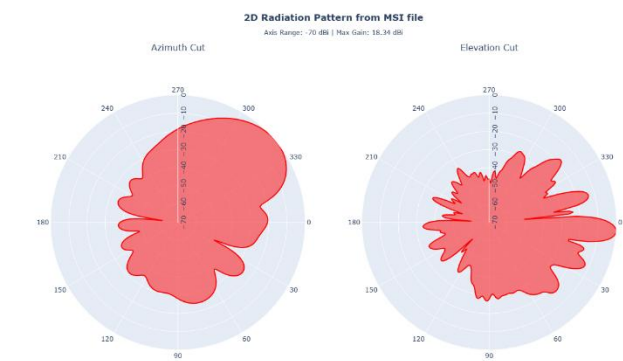


Fig.2 polar plot of .msi file

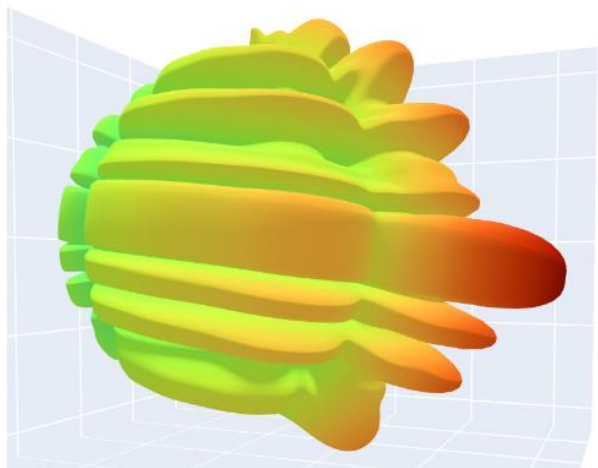


Fig.3 3D antenna pattern from .msi file

For visualization, these gain values are normalized and plotted in polar coordinates (Fig. 2), producing two distinct radiation diagrams: the H-plane pattern and the V-plane pattern. This representation preserves the vendor-specified beamwidth characteristics, including the half-power beamwidth (HPBW), while providing an intuitive means of comparing different frequencies or tilt configurations.

2.3. 3D PATTERN COMPUTATION

While MSI files provide only two-dimensional cuts, a complete analysis of antenna behavior requires reconstruction of the three-dimensional gain distribution. The proposed system combines the horizontal and vertical attenuation values to approximate the 3D antenna pattern (Fig. 3).

To obtain the three-dimensional radiation pattern of an antenna, several approaches have been proposed in prior works. One commonly used method is [2]. In this approach combines the horizontal and vertical patterns by adding their gain at a given azimuth and elevation angle. Please note that $G_H(\phi)$ and $G_V(\theta)$ are assumed to be in dB and normalized. Interpolated gain can be computed by

$$\hat{G}_{SA}(\theta, \phi) = G_H(\phi) + G_V(\theta), \quad (3)$$

where $\hat{G}_{SA}$ is the Interpolated gain. This approach is straightforward and computationally efficient, and it has been widely used in earlier studies. However, because it assumes that the overall 3D gain can be represented as the direct sum of two independent components often leads to inaccuracies.

A second approach is [3] which applying weighting factors to the horizontal and vertical patterns before combining them. In this method, the final 3D gain at a given angular coordinate is expressed as a weighted sum of the two components. Interpolated gain can be computed by

$$\hat{G}_{ws}(\theta, \phi) = \frac{[\phi_1 G_{\phi_2} + \phi_2 G_{\phi_1}] A_1 + [\theta_1 G_{\theta_2} + \theta_2 G_{\theta_1}] A_2}{[\phi_1 + \phi_2] A_1 + [\theta_1 + \theta_2] A_2} \quad (4)$$

where $\hat{G}_{ws}$ is the Interpolated gain and θ_1 and θ_2 are the angular distances between the point of interest $P(\theta, \phi)$ and the known $G_{\theta_1}(\phi)$ and $G_{\theta_2}(\phi)$ planes, respectively. Similarly, ϕ_1 and ϕ_2 are the angular distances for G_{ϕ_1} and G_{ϕ_2} planes. A_1 and A_2 are weight functions given by

$$\begin{cases} A_1 = \frac{\theta_1 \theta_2}{(\theta_1 + \theta_2)^2}, \\ A_2 = \frac{\phi_1 \phi_2}{(\phi_1 + \phi_2)^2}, \end{cases} \quad (5)$$

In this work, we adopt the [1] which builds upon the weighted summing method. The method reconstructs the 3D radiation pattern by combining the four principal planes ($G_{\theta_1}(\phi)$, $G_{\theta_2}(\phi)$, $G_{\phi_1}(\theta)$, $G_{\phi_2}(\theta)$) using specific weight functions that account for the relative angular distance of the observation point. The Interpolated gain can be computed by

$$\begin{cases} \hat{G}_{H_m}(\theta, \phi) = G_{\theta_1}(\phi) \cdot W_1(\theta) + G_{\theta_2}(\phi) \cdot [1 - W_1(\theta)], \\ \hat{G}_{V_m}(\theta, \phi) = G_{\phi_1}(\theta) \cdot W_2(\phi) + G_{\phi_2}(\theta) \cdot [1 - W_2(\phi)], \end{cases} \quad (6)$$

The weight function, define in

$$\begin{cases} W_1(\theta) = 1 - \frac{2|\theta|}{\pi}, \\ W_2(\phi) = 1 - \frac{|\phi|}{\pi}, \\ W_3(\theta, \phi) = \frac{2}{\pi} \left[\frac{\pi}{4} - |\theta| + \frac{\pi}{2} - \left(\frac{\pi}{2} - |\phi| \right) \right], \end{cases} \quad (7)$$

finally, the interpolated antenna gain $\hat{G}(\theta, \phi)$ is evaluated combining both $\hat{G}_{H_m}(\theta, \phi)$ and $\hat{G}_{V_m}(\theta, \phi)$ values, using the $W_3(\theta, \phi)$ weight function, according to

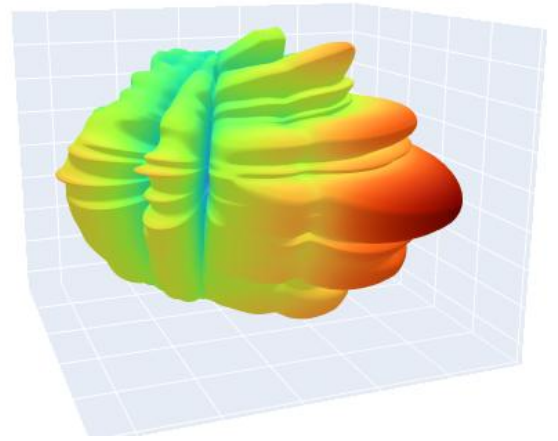
$$\hat{G}(\theta, \phi) = \hat{G}_{H_m}(\theta, \phi) \cdot W_3(\theta, \phi) + \hat{G}_{V_m}(\theta, \phi) \cdot [1 - W_3(\theta, \phi)]. \quad (8)$$

2.4. MODIFIED RADIATION PATTERN COMPUTATION

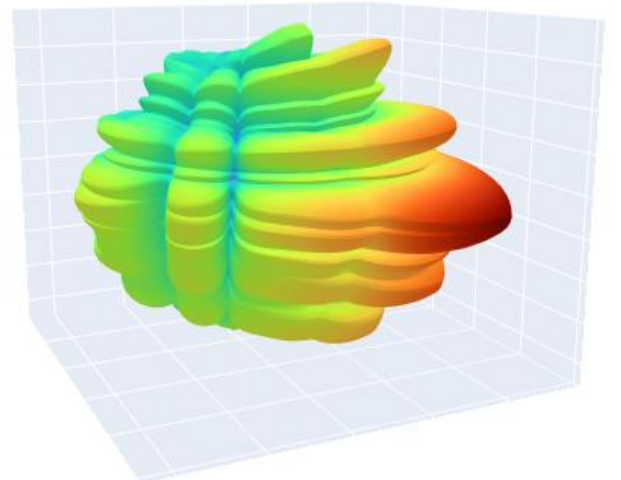
After testing [1] it seems that $W_3(\theta, \phi)$ has not been normalized as expected so we change the formula as follows.

$$W_3(\theta, \phi) = \frac{4}{3\pi} \left[\frac{\pi}{4} - |\theta| + \frac{\pi}{2} - \left(\frac{\pi}{2} - |\phi| \right) \right]. \quad (9)$$

In Fig. 4(a) illustrates the radiation pattern prior to normalization, while Fig. 4(b) shows the pattern after normalization. It can be observed that Fig. 4(a) exhibits a broader distribution with inflated side lobes, whereas Fig. 4(b) demonstrates a more compact main lobe and reduced energy spread.



(a) unmodified



(b) modified

Fig.4 Comparison Between unmodified weight and modified weight

3. ANTENNA DEPLOYMENT IN MOBILE COMMUNICATION SYSTEM

Beyond radiation pattern visualization, practical antenna performance depends on its placement within the environment and the position of users. The proposed system integrates antenna models with a geospatial mapping platform (Maplibre GL JS with MapTiler data), enabling deployment analysis in realistic urban scenarios.

3.1.1. ANTENNA AND RECEIVER PLACEMENT

Users can select antenna positions on building rooftops and receiver positions at street level by interacting with the map interface. Each placement is defined by geographic coordinates (x, y, h) , where h denotes the antenna or receiver height. The antenna orientation is specified by its azimuth bearing ϕ_0 and electrical/mechanical tilt θ_0 .

3.1.2. DISTANCE AND ANGULAR CALCULATIONS

Let the antenna be located at (x_a, y_a, h_a) and the receiver at (x_r, y_r, h_r) , the system computes 2D ground distance, define in

$$d_{2D} = \sqrt{(x_a - x_r)^2 + (y_a - y_r)^2}, \quad (10)$$

if x, y is in term of lat, lng we can calculate d_{2D} using a haversine formula as follows:

$$\begin{cases} a = \sin^2\left(\frac{\Delta x}{2}\right) + \cos(x_a) \cdot \cos(x_r) \cdot \sin^2\left(\frac{\Delta y}{2}\right), \\ c = 2 \arctan\left(\sqrt{a}, \sqrt{1-a}\right), \\ d_{2D} = R \cdot c, \end{cases} \quad (11)$$

where R is earth's radius. Height difference, define in

$$\Delta h = h_a - h_r, \quad (12)$$

3D distance, define in

$$d_{3D} = \sqrt{d_{2D}^2 + (\Delta h)^2}, \quad (13)$$

azimuth bearing to receiver, define in

$$\phi = \tan^{-1}\left(\frac{y_r - y_a}{x_r - x_a}\right), \quad (14)$$

elevation angle, define in

$$\theta = \tan^{-1}\left(\frac{\Delta h}{d_{2D}}\right). \quad (15)$$

3.1.3. GAIN COMPUTATION AT RECEIVER

The effective antenna gain at the receiver location is obtained from (8):

$$G_{rx} = G(\theta - \theta_0, \phi - \phi_0), \quad (16)$$

where G_{rx} represent receiver's gain and θ_0 and ϕ_0 represent the antenna's electrical/mechanical tilt and azimuth orientation, respectively.

3.1.4. HALF POWER BEAM WIDTH

The HPBW is defined as the angular region in which the antenna gain remains within 3 dB of its maximum value.

Mathematically, if $G(\alpha)$ denotes the antenna gain as a function of angle α (where α may be azimuth ϕ for the horizontal plane or elevation θ for the vertical plane), then the HPBW is given by:

$$\text{HPBW} = \alpha_2 - \alpha_1. \quad (17)$$

where $G(\alpha_1) = G(\alpha_2) = G_{\max} - 3\text{dB}$. These values provide a quick estimation of the coverage footprint, since the HPBW represents the angular extent of the main lobe where the radiated power remains within 50% of its peak.

You can calculate the range of HPBW of each plane by using this formula, the horizontal HPBW range (d_{3dB}^+ , d_{3dB}^-) defines in

$$\begin{cases} d_{3dB}^+ = \frac{\Delta h}{\tan(\theta_m + \frac{\theta_{V-HPB}}{2})}, \\ d_{3dB}^- = \frac{\Delta h}{\tan(\theta_m - \frac{\theta_{V-HPB}}{2})}, \end{cases} \quad (18)$$

where is the θ_m mechanical tilt and θ_{V-HPB} is a HPBW of vertical plane, the vertical HPBW range (ϕ_{3dB}^+ , ϕ_{3dB}^-) defines in

$$\begin{cases} \phi_{3dB}^- = \phi - \frac{\theta_{H-HPB}}{2}, \\ \phi_{3dB}^+ = \phi + \frac{\theta_{H-HPB}}{2}, \end{cases} \quad (19)$$

where θ_{H-HPB} is a HPBW of horizontal plane. This range will be used to determine the effective range of antenna radiation and will be show on third page of the interface.

4. DEPLOYMENT AND CALCULATION PARAMETERS

The system displays computed parameters in real time, including 2D/3D distance, height difference,

azimuth, elevation, and G_{rx} . Users can adjust antenna tilt, orientation, and placement to observe immediate changes in coverage and beam alignment. This functionality constitutes the third page of the interface, bridging theoretical antenna models with practical deployment considerations.

Beyond MSI specifications, realistic visualization requires environmental and deployment-related inputs, such as antenna height, receiver height, and antenna bearing. These parameters can be modified by the user to study different deployment scenarios. Additionally, the tool dynamically computes derived quantities such as distance, azimuth, elevation, and effective gain at the receiver location. Table II presents the deployment and calculation parameters considered in this work.

TABLE II. Deployment and Calculation Parameters

Parameter	Value / Range	Notes
Antenna height	5-100 m	Not including building height
Receiver height	1.5-2.5 m	Average user equipment level
Antenna bearing (azimuth)	0°-359°	Default from MSI, user-adjustable
Mechanical tilt	-45°-45°	User-adjustable
2D distance	Derived	Computed from antenna–receiver positions
3D distance	Derived	(11)
Height difference	Derived	(10)
Bearing	Derived	Calculated from map coordinates
Gain	Derived	G_{RX} from 3D pattern

In this manner, the deployment and calculation parameters allow flexible configuration of scenarios and interactive exploration of antenna performance within the proposed tool.

5. DATA VISUALIZATION AND RESULT

The proposed system provides three distinct modes of visualization, corresponding to separate pages in the web-based interface. These include 2D radiation pattern visualization, 3D antenna radiation modeling, and 3D simulated scene and lastly geospatial deployment with interactive parameter adjustment. Together, these visualization modes provide both analytical and practical insights into antenna performance.

5.1. 2D RADIATION PATTERN VISUALIZATION

In the proposed tool, 2D radiation patterns

constitute the first page of the interface, serving as the baseline representation of antenna characteristics. Users can interactively examine H-plane and V-plane plots, zoom into specific angular regions, and compare multiple MSI configurations in real time.

The first page of the system interface displays the horizontal (H-plane) and vertical (V-plane) radiation patterns extracted directly from the MSI file. The gain values are plotted in polar form to reflect the directional characteristics of the antenna. Fig. 5 illustrates the horizontal (H-plane) and vertical (V-plane) radiation patterns for the tested antenna. The horizontal pattern demonstrates a beamwidth of 36°, while the vertical pattern exhibits a beamwidth of 7°. The results confirm that the tool successfully parses MSI data and renders vendor-specified polar plots.

5.2. 3D RADIATION PATTERN VISUALIZATION

3D visualization forms the second page of the interface, enabling users to interactively rotate, zoom, and examine antenna directivity in three dimensions. MSI-derived 2D patterns turn into a full three-dimensional representation of antenna gain.

To provide clear and interactive context for our data, a three-dimensional scene was established using Three.js. This virtual environment serves as the canvas for rendering complex simulations, including antenna radiation patterns and their spatial interactions which are Antenna Pole and Person.

Fig. 6 presents the 3D radiation pattern, computed using the method described in (8). The 3D radiation pattern has been put on an antenna pole. Users can adjust the height of the antenna pole to simulate different tower configurations, change the height of the person model to represent different user equipment levels, and vary the distance between the person and the antenna.

5.3. 3D GEOSPATIAL VISUALIZATION

The third page integrates antenna models and 3D visualization forms with a geospatial environment. Using Maplibre GL JS and MapTiler data, antennas can be virtually placed on buildings, while receiver positions can be defined on streets or rooftops. The system computes deployment-specific parameters such as: 2D and 3D distance between antenna and receiver, height difference (Δh) azimuth bearing (ϕ) and elevation angle (θ), Effective gain at the receiver (G_{RX}) and HPBW

Users can interactively modify antenna bearing, mechanical tilt, and location to observe how these adjustments impact coverage and gain distribution in real time.

Fig. 7 shows the geospatial deployment page, where the antenna is positioned on a building rooftop and a receiver is placed at street level. This figure also includes 3D pattern radiation, corresponding to the region of effective coverage. In the visualization, the ± 3 dB zone is projected onto the geospatial envi-

ronment, enabling users to observe how the antenna's main beam intersects with user and building. This feature bridges the vendor-defined antenna pattern with practical deployment insight, providing an intuitive representation of the effective service region in real environments.

6. CONCLUSION

In this paper, we presented a web-based visualization tool for analyzing antenna radiation patterns in mobile communication systems. The tool enables users to upload MSI files, visualize horizontal and vertical radiation cuts in two dimensions, reconstruct three-dimensional gain distributions using (8), and integrate antenna deployments within a 3D scene and geospatial environment. By separating antenna specifications from deployment parameters, the system provides both technical accuracy and interactive flexibility.

The significance of the proposed tool lies in its ability to bridge the gap between theoretical antenna specifications and practical deployment scenarios. By offering a geospatially integrated and interactive visualization platform, it supports engineers, researchers, and students in exploring the effects of antenna parameters on coverage and performance.



Fig.5 2D Radiation Pattern Page



Fig.6 3D Radiation Pattern Page

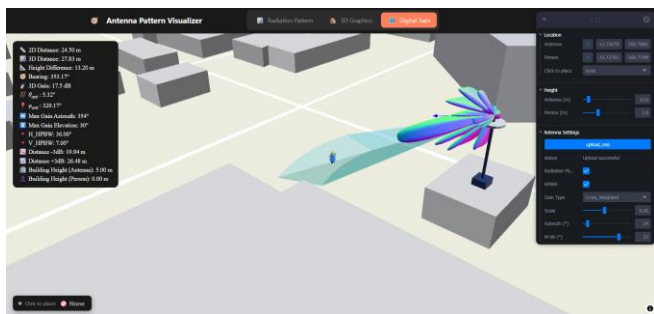


Fig.7 3D Geospatial page

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