The Effect of Vegetation on the Propagation Loss of V2I Network in High Altitude and Mountainous Area

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Abstract**—**With the gradual formation of the commercialization of the fifth-generation communication technology, the Internet of Vehicles technology has developed rapidly, and the vehicle to infrastructure (V2I) network technology is an important part of the Internet of Vehicles. In high-altitude and mountainous areas, the communication quality of the V2I network is not only affected by terrain, but forest vegetation will also cause greater propagation loss. Aiming at the influence of vegetation in high-altitude and mountainous complex environment on the propagation loss of V2I network, this paper establishes an equivalent model of vegetation in high-altitude and mountainous areas, and analyzes the relationship between propagation loss, propagation distance and frequency of transmitting antenna. At the same time, through digital elevation model (DEM) data and triangulated irregular network (TIN), MATLAB was used to simulate the communication coverage of V2I network in the complex area covered by vegetation, and the influence of vegetation on the propagation loss of V2I network in high altitude and mountainous areas was obtained. In the future, constructing the Internet of Vehicles in a complex environment, the results of research in this article will provide a scientific basis for network quality with high reliability and low latency.

Index Terms**—**High altitude and mountainous areas, V2I network, vegetation, propagation loss

I. INTRODUCTION

At present, with the continuous growth of vehicle ownership in our country and the increasingly saturated road carrying capacity, the Internet of Vehicles is considered to be the typical application scenario and best use case of "5G + Internet of Things" [1]. V2I refers to the communication between the vehicle and the roadside unit, that is, the telecommunication infrastructure and other network facilities [2]. In this way, the vehicle and the cellular network base station are connected to the Internet to obtain traffic information in the nearby area, based on the information integration to provide corresponding guidance and warning services to drivers[3]. Compared with mobile phones and mobile terminals, vehicles have higher requirements for communication quality. The construction of V2I networks requires higher reliability, lower latency and higher throughput. Therefore, the propagation loss prediction of V2I networks is more important, especially at high altitudes and mountainous complex area.

The height of the high-altitude mountainous area defined in this article is between 1500 meters and 3500 meters. In the high-altitude and mountainous complex environment, it is often a complex forest area covered by vegetation, and the occlusion, scattering and absorption caused by vegetation such as trees can produce large propagation losses. Therefore, the research and analysis of radio wave propagation loss in vegetation play a realistic and important role for V2I networks in high-altitude mountainous areas under vegetation coverage.

The rest of this paper is structured as follows: In section II, based on the model of the target area, the system model map, the vegetation equivalent model map of mountainous area and TIN Irregular Triangular Mesh Division Principle are given. In section III, the propagation model and the propagation principle are analyzed. Based on the equivalent model proposed in section II, the basic propagation loss formula caused by vegetation and the transmission loss of O2I vehicle are obtained. In section IV, the communication quality coverage of the target area is predicted by Matlab simulation, and the relationship between the basic propagation loss caused by vegetation and the propagation distance and the frequency of the transmitter antenna is analyzed, finally, the effect of vegetation on V2I network propagation loss in high altitude and mountainous area is obtained. In section V，we come to conclusion.

II. MODEL ESTABLISHMENT

A. System Model

Firstly, we build a model of the target environment. As shown in Fig. 1, the target area is located in a high-altitude mountainous area and covered with original vegetation. In order to establish a smooth V2I communication network and reduce propagation loss, the

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transmitter is located at the top of a high-altitude mountain and within the vegetation layer. In a high-altitude complex environment, in addition to the topography, the original vegetation and forests are also critical to the propagation loss of the V2I network. The establishment of the system model facilitates our further discussion of research issues.

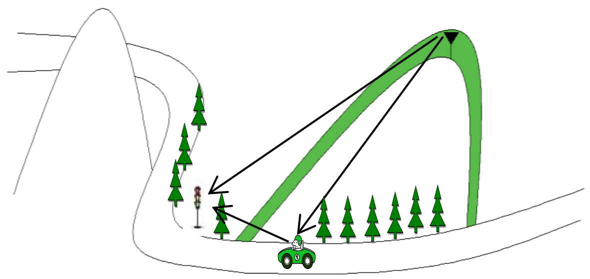


Fig. 1. V2I network model of high altitude mountain highway with dense vegetation coverage

B. Equivalent Model

In order to accurately study the influence of vegetation on the propagation loss of the V2I network, we used the Tamir [4] vegetation model based on the consideration of complex terrain, as shown in Fig. 2 (a), and established an equivalent vegetation model in mountainous areas, as shown in Fig. 2 (b). We equate vegetation to layered lossy media, which are ground layer, vegetation layer and air layer. Each layer has different electrical parameters, and the layered idea is used to solve the problem.

Among them, in Fig. 2 (a), h is the height of the vegetation, the relative permittivity of the forest medium is $\varepsilon_1=n^2$,the relative permittivity of the ground is $\varepsilon_2=N^2$, n and N mean the complex refractive index of the forest and the ground respectively, Z_0 represents the height of the receiver, when $Z_0 > h$, it means that the receiver is above the vegetation layer; when $Z_0 < h$, it means that it is located within the vegetation layer [5].

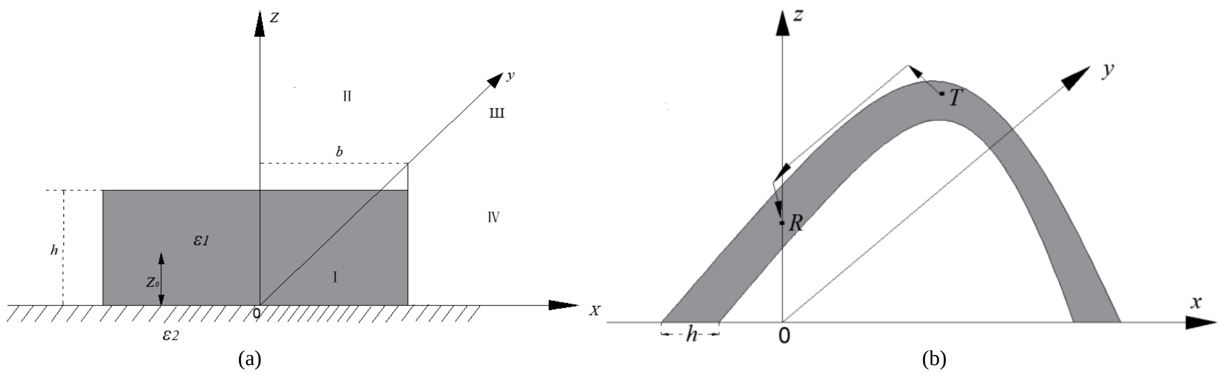


Fig. 2. Tamir vegetation model and equivalent vegetation model in mountainous areas

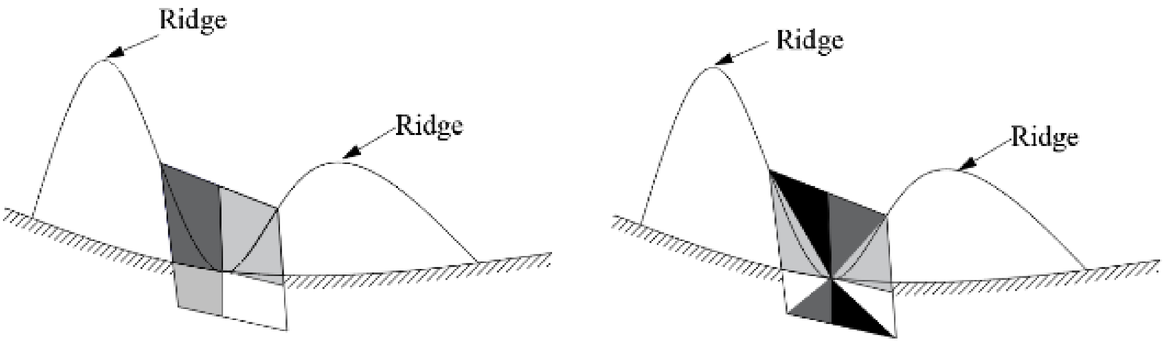
In a high-altitude and multi-mountainous scene, when building a propagation model, the transmitter is located at point T in the vegetation layer, and the receiver is located at point R in the vegetation layer, as shown in Fig. 2 (b). Because electromagnetic waves are mainly affected by side waves when they propagate in forests over long distances [6], this article focuses on the propagation loss of side waves when both V2I network transmitters and receivers are in the vegetation layer.

C. TIN Network

Triangular irregular network is a method of finely modeling complex terrain [7]. The difference between triangulated irregular network and traditional methods is that the density of sampling points changes and the location of sampling points is determined by the complexity of the terrain fluctuations. In areas with drastic terrain changes, variable point density can be used to generate an efficient and accurate surface model, as shown in Fig. 3.

TIN grid data is a collection related to the three-dimensional coordinates of each DEM sampling point. These points are connected by lines to form triangles without overlap. Therefore, TIN data must not only store the elevation of each point, but also store its plane. Coordinates, topological relationships of node connections, triangles, and adjacent triangles. TIN network data structure information and connection diagram are shown in Fig. 4.

In this paper, a Triangulated Irregular Network (TIN) is used to finely divide the ground surface to restore the true topography to the greatest extent, and accurately obtain the influence of vegetation on the propagation loss of the V2I network. At the same time, it can avoid data redundancy in flat terrain, and can represent digital elevation features according to terrain features (ridges, valley lines, etc.). In high-altitude and mountainous areas, variable point densities can be used to generate an efficient and accurate surface model. Use the triangulation algorithm [8] to generate the TIN grid as shown in Fig. 5.



(a).Traditional quadrilateral gird (b). TIN gird

Fig. 3. Traditional quadrilateral gird & TIN grid

Node number	Node coordinates	Triangle name	Adjacent triangles	Adjacent nodes
1	x_1,y_1,z_1	A	B,E	1,2,4
2	x_2,y_2,z_2	B	A,C	2,3,4
3	x_3,y_3,z_3	C	H,B	3,4,8
4	x_4,y_4,z_4	D	E,G,H	4,5,7
5	x_5,y_5,z_5	E	A,D,F	1,4,5
6	x_6,y_6,z_6	F	E,G	1,5,6
7	x_7,y_7,z_7	G	F,D	5,6,7
8	x_8,y_8,z_8	H	C,D	4,7,8

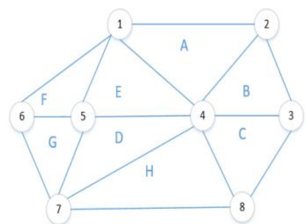


Fig. 4. TIN grid data structure information and connection diagram

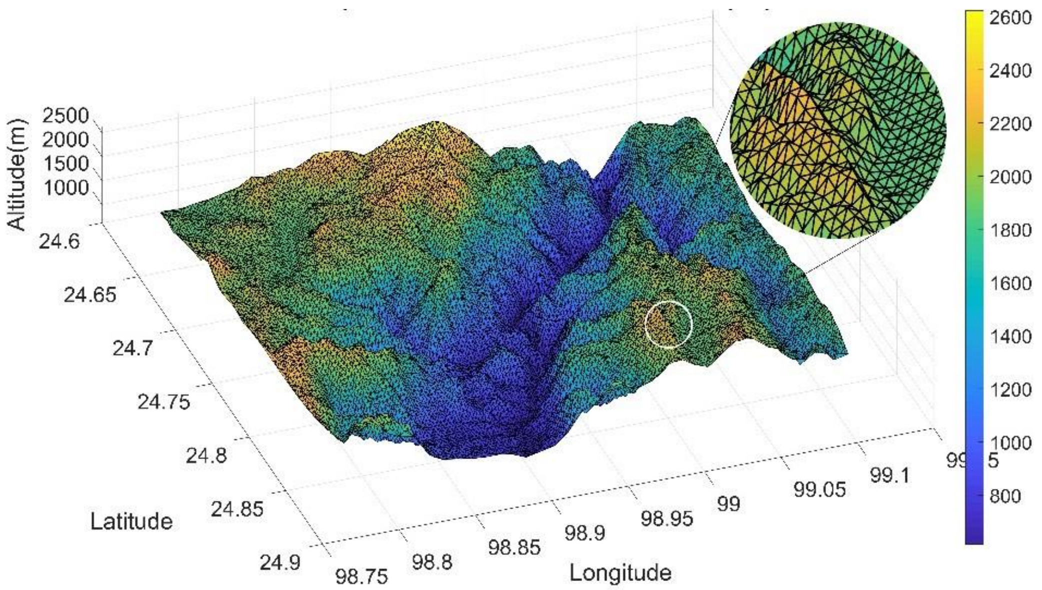


Fig. 5. TIN grid visualization

III. Propagation Model and Principle

A. *Calculation of the Effective Antenna Height of the Transmitter*

In the mountainous environment, the conventional equivalent method of calculating the effective antenna height of the transmitter is obviously no longer suitable. There are two major disadvantages: h_T, the effective height of the transmitter has a large error; *d*, the propagation distance *d* has a large error. And the greater the ups and downs of the mountains, the greater the error. In order to reduce this error, this section establishes a calculation model for the effective antenna height of the transmitter in high-altitude and mountainous areas, as shown in Fig. 6.

Among them, h_T is the actual height of the transmitter, h_R is the actual height of the receiver, ASL represents the altitude above sea level, the ground altitude of the transmitter is expressed as $h_{T,ASL}$, and the ground altitude of the receiver is expressed as $h_{R,ASL}$. The calculation formula for the effective antenna height of the transmitter h_b is:

$$h_b = h_{T,ASL} + h_T - h_{R,ASL} \tag{1}$$

The propagation distance, d is expressed as:

$$d = \sqrt{(T_x - R_x)^2 + (h_b - h_R)^2} \tag{2}$$

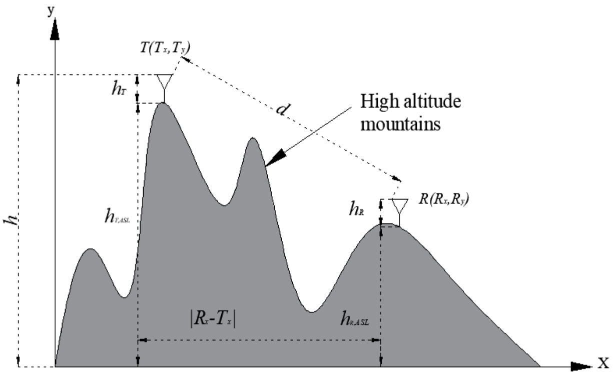


Fig. 6. Altitude calculation model of wired antenna for transmitter in high altitude mountainous region

B. *Field Expression of Side Wave*

As shown in Fig. 7, the complex forest environment is treated in a layered equivalent manner in this paper, the effective dyadic dielectric constant, $\bar{\varepsilon}$ is used to replace the forest scatterer with an equivalent continuum, the time relationship, the first-order saddle point method and the boundary conditions of electromagnetic fields conditions are used to obtain $\tilde{E}_I$, the signal strength expression of the side wave when using a dipole antenna [9].

$$\tilde{E}_I = \frac{60Il}{(n^2-1)d^2} e^{j[kd + k_L(2h - h_T - h_R)]} F(90^\circ,\ z_0) \tag{3}$$

Among them, Il is the dipole moment, $k = \frac{2\pi}{\lambda} = 2\pi f(\mu_0\varepsilon_0)^{1/2}$ is the propagation factor of the plane wave in the air, f is the radiation frequency, μ_0 is the permeability of the air, ε_0 is the permittivity of the air, $k_L = k(n^2-1)^{1/2}$, and other geometric parameters are described in Fig. 7, and the factor $F(90^\circ, z)$ in Eq. (3) describes the reflection coefficient of the ground plane, in this case, $F(90^\circ, z) = 1$.

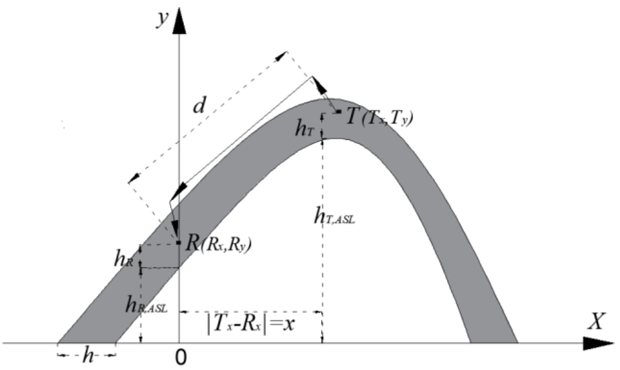


Fig. 7. Schematic diagram of side wave propagation

C. *Propagation Loss Calculation*

In this article, for the propagation loss of the V2I network under the above conditions, in addition to the basic propagation loss caused by vegetation, the propagation loss of electromagnetic waves also includes O2I vehicle penetration loss and loss caused by Doppler frequency shift, but the propagation loss caused by the Doppler frequency shift is negligible compared with the former two, so this article will not discuss the Doppler frequency shift, therefore, the sum of the first two is the propagation loss of the entire path: $P_L = P_{L_0} + P_{L_1}$.

1) *Basic propagation loss*

Under the above conditions, the effective receiving efficiency of the dipole antenna in the forest vegetation is:

$$P_r = \frac{\left|\tilde{E}_I\right|^2 \lambda^2}{320\pi^2} = \frac{45}{4\pi^2}\left(\frac{Il\lambda}{\left(n^2-1\right)d^2}\right)^2 \tag{4}$$

Among them, in Fig. 7, the propagation distance is: $d = \sqrt{x^2 + (h_b - h_R)^2}$. The transmit power is:

$$P_t = 80\pi^2\left(\frac{Il}{\lambda}\right)^2 \tag{5}$$

Therefore, the basic loss, P_{L_0} can be expressed as:

$$\begin{aligned} P_{L_0} &= 10\log\frac{P_t}{P_r} \\ &= 20\log\left[\frac{8}{3}\pi^2\left|n^2-1\right|\left(\frac{\sqrt{x^2+(h_b-h_R)^2}}{\lambda}\right)^2\right](dB) \end{aligned} \tag{6}$$

It can be seen from Eq. (6) that the basic loss is determined by the horizontal distance and height difference between the transmitter and the receiver, the forest conductivity and the transmitter antenna frequency.

2) *O2I vehicle penetration loss*

In the V2I network, the receiver is located inside the vehicle, so O2I vehicle penetration loss should be included. The path loss model of O2I vehicle penetration loss is as follows [10]:

$$\mathrm{P}_L = \mathrm{P}_{L_0} + N(\mu, \sigma_p^2) \tag{7}$$

Among them P_{L_0} is the basic loss of the above formula. The vehicle penetration loss should be specially given by the receiver. However, due to different materials such as car windows, we generally take 10dB and follow a normal distribution $N(10, 5^2)$.

By combining the above basic propagation loss and O2I penetration loss analysis, the total propagation loss can be expressed as:

$$P_L = 20\log\left[\frac{8}{3}\pi^2\left|n^2-1\right|\left(\frac{\sqrt{x^2+(h_b-h_R)^2}}{\lambda}\right)^2\right] + 10(dB) \tag{8}$$

IV. BASIC PROPAGATION LOSS SIMULATION PREDICTION

In order to acquire the influence of vegetation on the propagation loss of the V2I network in the target area, we simulated the propagation loss diagram of the area with or without vegetation, as shown in Fig. 8. Firstly, we perform TIN fine meshing on the DEM data of the target area, and use the above-mentioned total propagation loss Eq. (8) to predict the communication coverage of the V2I network in the area, and set the refractive index of the ground and vegetation to $N^2 = 10 + i$, $n^2 = 1.02 + 0.02i$. For convenience, the polarization mode of the transmitting antenna is vertical polarization [11], and the frequency of the transmitter antenna is 2 GHz. This article assumes that when the propagation loss is less than 160 dB, the receiver can reliably sense the transmitter signal, that is, the vehicle can communicate normally.

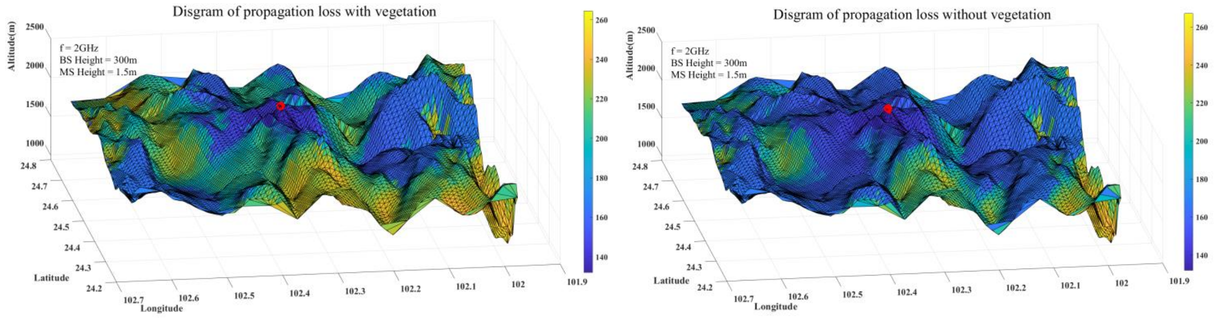


Fig. 8. Simulation results. (a). Diagram of propagation loss with vegetation. (b). Diagram of propagation loss without vegetation, and the color bar on the rights shows the PL prediction value in dB.

As shown in Fig. 8, we can see the propagation loss prediction simulation with or without vegetation coverage, but it's difficult to reflect the specific situation of the impact of vegetation on the propagation loss of the V2I network in the figure. Therefore, based on the schematic diagram of the propagation loss, we obtained a graph of the loss comparison with or without vegetation under different conditions (horizontal distance and transmitter antenna frequency) through calculation and analysis, as shown in Fig. 9.

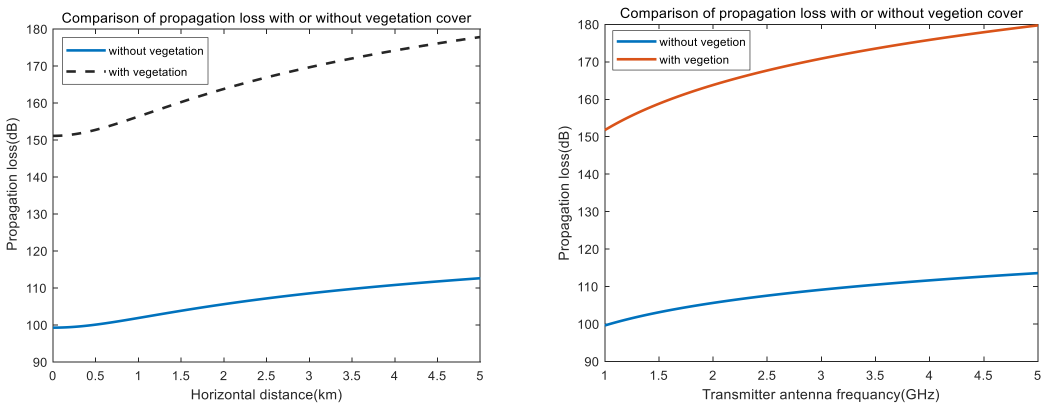


Fig. 9. Comparison of propagation loss. (a). The relationship between propagation loss and propagation distance. (b). The between propagation loss and transmitter antenna frequency.

It can be seen from Fig. 9 that the basic propagation loss of the V2I network will increase as the propagation distance of electromagnetic waves in vegetation and the frequency of the transmitter antenna increase. It can be seen from Fig. 9 (a) that when the transmitter antenna frequency is fixed at 2 GHz, as the horizontal distance increases, the propagation loss caused by vegetation is slowly rising between 50 dB and 70 dB. In Fig. 9 (b), when the horizontal propagation distance is 2km, the propagation loss curve with or without vegetation is basically the same as Fig. 9 (a).

Through the prediction and simulation results, we can not only visually see how vegetation covers the communication quality of the V2I network in the target area, but also verify the basic propagation loss caused by the vegetation on the radio wave propagation under different conditions. When there is no vegetation in the area that affects the V2I network, the basic propagation loss is affected by the terrain, and only a few areas cannot meet the normal communication quality. However, it will be affected by the terrain and vegetation when blocked by vegetation, so most areas cannot meet the normal quality of communication. Through the propagation loss prediction simulation, it provides theoretical guidance for the actual deployment of antenna selection, power setting and site selection when deploying a V2I network in a complex terrain and multi-vegetation environment.

V. CONCLUSION

The prediction loss of radio wave propagation in high-altitude, mountainous and complex areas has always been a complex problem. Related research on this problem generally focuses on channel detection or simple theoretical hypothesis analysis. This paper focus on the propagation loss of the V2I network of vegetation in high-altitude and mountainous areas. Based on the Tamir vegetation model, the effective dyadic permittivity is used to equivalently dispose the vegetation in high-altitude mountainous areas. When both the transmitter and the receiver are located in the vegetation layer, the effect of vegetation on the propagation loss of electromagnetic waves is obtained. Using the first-order saddle point method and the boundary conditions of the electromagnetic field to obtain the signal strength of the side wave when using a dipole antenna, and obtain the basic propagation loss of vegetation. The basic propagation loss of O2I vehicle is analyzed, and the total propagation loss is obtained. Through simulation, combined with DEM data and TIN irregular triangulation, the terrain was restored to the greatest extent. We analyzed the relationship between horizontal distance and transmitting antenna frequency and basic propagation loss, this result is applicable to the effects of vegetation in different environments on propagation loss, and has a guiding role in the construction of V2I networks for the Internet of Vehicles in high-altitude and mountainous areas, there are also of great significance in communication and electronic countermeasures in military operations in complex environments.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Dongjie Xie, Rong Guo conducted the research; Huafu Li, Yanmei Jing and Wenxue He analyzed the data; Dongjie Xie, Rong Guo wrote the paper; all authors had approved the final version.

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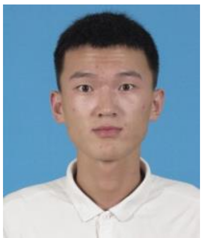

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