Study of Characteristic Prediction of Radio Wave Propagation Loss on Complex Irregular Terrain of Wide-range Distance

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Abstract—**Common radio wave propagation models are very theoretical and restrict. They are not suitable to apply to general propagation environments. And the calculation process is too complicated to apply in engineering conveniently. Summary of the previous researches, this paper considered the theory of radio wave propagation models about distance from the hundreds of meters to hundreds of kilometers. One prediction method for characteristic of radio wave propagation loss on complex irregular terrain is proposed. This paper used real topographic information of the SRTM-DEM(Shuttle Radar Topography Mission-Digital Elevation Model) data and extracted the path profile information to analyze the point-to-point communication propagation path loss. The simulation results prove that the prediction method is valid within the frequency range from 400MHz to 20GHz.**

Keywords- radio wave propagation; complex irregular terrain; path loss; SRTM-DEM

I. INTRODUCTION

Radio wave propagation theory is a timeless research topic. A number of models have been developed for prediction over the years. The study of radio wave propagation loss is in order to understand the channel characteristics of wireless communications and to construct the corresponding model to guide and achieve an effective high data rate communication system. These models can be categorized into two main approaches: empirical and deterministic. Empirical models are based on vast amounts of actual measurements, while deterministic models utilize the laws of electromagnetic waves to determine a number of parameters, including the phase and signal strength of the wave at a particular domain of interest or area. Deterministic models often require extensive knowledge about the terrain in the form of three dimensional maps, aerial photography or satellite pictures [1].

A good radio propagation model must meet both two requirements, which are high accuracy and low calculation cost. In order to take into account both requirements in radio wave propagation model, the study is based on ITU(International Telecommunication Union)R-P recommendations and ITS (Institute for Telecommunication Sciences) Irregular Terrain Model algorithm but it simplifies them. Meanwhile, study makes no sense under purely ideal conditions, for example assuming that there is a mountain and a valley in the path detached from the real geographical environment. With the rapid development of GIS(Geographic Information System), environmental parameters such as surface elevation and surface electromagnetic parameters can be extracted from digital maps. Thus the whole analysis uses the data of SRTM-DEM in this paper.

Several studies and researches have been made on ground radio wave propagation, however they are not always simple and efficient to use when radio wave propagation is along complex irregular terrains of wide-range distance. The author introduces a new prediction path loss method below.

II. EXTRACT COMPLEX IRREGULAR TERRAIN PROFILE

The SRTM data products result from a collaborative mission by the NASA(National Aeronautics and Space Administration), the NIMA(National Imagery and Mapping Agency), the DLR(Deutsches Zentrum fur Luft-und Raumfahrt, namely German space agency) and ASI(Agenzia Spaziale Italiana, namely Italian space agency), to generate a DEM of the Earth using satellite radar interferometry. DEM is a computer representation of the Earth's surface, and it provides a base dataset from which topographic parameters can be digitally generated.

A. SRTM-DEM data

The SRTM collected three-dimensional measurements of the Earth's surface using radar interferometry, which compares two radar images taken at slightly different location to obtain elevation information. The collected radar images were converted to DEM spanning the globe between 60°N and 58°S latitude. The "virtual Earth" is reconstructed as a mesh of 30m spacing, and it is accompanied for each point by a measure of the reflected energy of the radar signal, the intensity image.

The memorandum of understanding between NASA and NIMA for STRM specifies that data will be processed at

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3"(90m) for any point on Earth and made available unrestricted, as will the 1"(30m) data for the United States and its territories. 3" means data points located at every 3" on a latitude/longitude grid, approximately 90 meters. Distribution of 1" data for outside the United States is approved by NIMA on a case-by-case basis, for NASA investigators, for their use only. The overall estimation for the absolute horizontal and vertical accuracy is 20 and 16m, respectively in a 90% confidence interval [2].

B. Correct Profile Using Curvature of Earth

From the SRTM-DEM data on the lines of communication elevation height value H_n, plotted Fig. 1 is shown on the above. But it has not considered the curvature of Earth. In fact, when the communication distance is equal to 20 km, the Earth bulge height of the middle point of the communication line is 8 m; when the communication distance increases to 40 km, the Earth raised height of the middle point up to 31m.

Considered the terrain profile after curvature of Earth correction, it will properly distinguish the spread of types of communication lines. Along the lines of communication elevation height value bulged from the ground is calculated by the following formula:

$$\Delta H_n = d_n\left(d-d_n\right)/2a_e, (n=1,2,\cdots,\mathrm{N}) \qquad (1)$$

Where d is the communication distance, a_e is equivalent radius after considered the effect of atmospheric refraction. The figure terrain profile after curvature of Earth correction plotted in Fig. 1 is shown on the below.

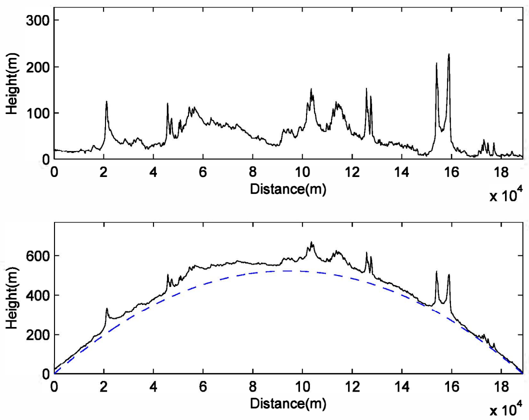


Figure 1 Terrain Profile, Terrain Profile after Curvature of Earth Correction

III. Propagation Loss Prediction Calculate Method

The radio wave propagation is mainly affected by topography and troposphere. It is the major impacts of the topography that the multipath interference effect from direct wave and ground reflected and the diffraction effect from mountains and tall buildings. The impacts of the atmosphere are mainly in the radio wave refraction and scattering effect [3].

A. Prediction Process

During the prediction process, the geographical location of transceiver, antenna parameters, atmosphere parameters, transmission frequency and other information are used to calculate the geometric link, line-of-sight and effective propagation distance and intermediate parameters. Propagation prediction process is shown in Fig. 2.

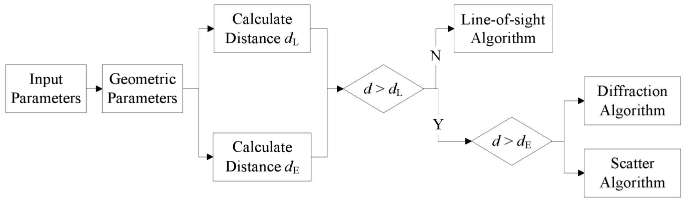


Figure 2 Sketch of Propagation Loss Prediction Process

According to latitude and longitude of the transceiver antennas geographic location, this paper extracts surface elevation data at different locations propagation path from SRTM-DEM data. According to the heights of transceiver antennas, radio frequency and elevation data, calculates the terrain irregularity parameter Δh on every position on the spread of the propagation path, the line-of-sight propagation distance d_L and the effective propagation distance d_E. The three intervals defined here are called the line-of-sight, diffraction, and scatter regions respectively. If the propagation distance d is bigger than d_L, prediction loss method is the line-of-sight propagation algorithm. If the propagation distance d is bigger than d_E, prediction loss method is the diffraction propagation algorithm. In addition to both, it is the scatter propagation algorithm [4].

B. Line-of-sight Propagation Algorithm

In the line-of-sight region, attenuation loss is performance as a weighted average from multipath interference loss and surface diffraction loss. Multipath interference loss described by random process, thus the result of prediction is occuring with a certain probability [5]. The following formula gives a simple way to calculate the loss A_M in probability of more than percentage of time P.

$$A_M = -10\log\left(P/Kd^{3.4}\left(1+\left|\varepsilon_p\right|^{-1.03} f^{0.8}\right)\right) - 0.0076h_L \qquad (2)$$

Where K is calculated by surface refractivity, f is the frequency, h_L is the lower height between transmitter and receiver.

Since no obstructions block the line-of-sight propagation, the terrain irregularity parameter Δh is always negative. Surface diffraction loss changes from the maximum value in blade-shaped obstacles to the maximum value in a smooth spherical earth.

The following formula gives the way to calculate the diffraction loss A_d:

$$A_d = -20\Delta h_{\max}/F_1 + 10 \qquad (3)$$

Where Δh_{max} is the max of Δh, F_1 is the radius of the first Fresnel ellipsoid.

C. Diffraction Propagation Algorithm

Diffraction region is where radio wave propagation path is blocked by mountains and tall buildings. There is no line-of-sight propagation condition. Diffraction propagation algorithm is in dependent topographic information, two main parameters

Fresnel integral comprehensive V and terrain irregularity parameter Δh [6]. When Δh is less than 0.557 of F_1, the propagation line is obscured. Fresnel integral comprehensive V is determined by:

$$V = \Delta h \sqrt{fd / \left(150 \times d_i \left(d - d_i\right)\right)} \qquad (4)$$

Where d_i is the distance between the transmitter and the obstacle, Δh is the terrain irregularity parameter.

The following formula gives the way to calculate the diffraction loss A_d:

$$A_d = 6.9 + 20\log\left(\sqrt{(V-0.1)^2+1} + V - 0.1\right) \qquad (5)$$

It is necessary to judge which obstacle will affect radio propagation when there are a number of obstacles in the path. Fig. 3 shows three peaks in diffraction line of profile. Despite there are lots of obstacles above the line of sight, the real influential points of the radio propagation is only three. There are four polyline representing the track of the radio wave propagation.

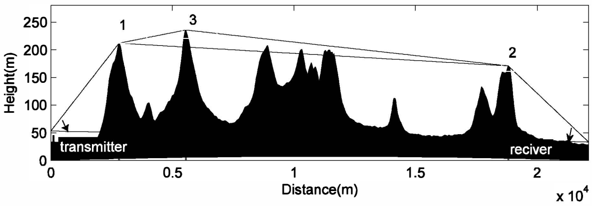


Figure 3 Three Peaks in the Diffraction Line of Communication Profile.

The approach to find the influential point is that starting from transmitter and receiver, calculating along the lines of communication point of ray elevation angles α and β, to identify the max of both α_{max} and β_{max} (point 1 and 2 for example in Fig. 3). And then from point 1 and 2, look for the influential points which are in the relative max elevation angles(point 3 for example in Fig. 3) and so forth. Added the loss of all influential peaks together, it constitutes the total loss of the diffraction line.

D. Scatter Propagation Algorithm

Compared with the line-of-sight and diffraction communication, the biggest advantage of the scattering communication is the long transmission distance [7]. Scatter propagation prediction is closed related with climate conditions.

TABLE I. CLIMATE CONDITIONS PARAMETER TABLE

Climate Zone	A_m (dB)	γ (1/km)	N_s (N-units)
Equatorial (Congo)	39.60	0.33	360
Continental Subtropical (Sudan)	29.73	0.27	320
Maritime Subtropical (Philippines)	19.30	0.32	370
Desert (Sahara)	38.50	0.27	280
Mediterranean	38.50	0.27	
Continental Temperate (USA)	29.73	0.27	301
Maritime Temperate, over land (UK)	33.20	0.27	320
Maritime Temperate, over sea	26.00	0.27	350
Polar	33.20	0.27	

It should be noted that the loss of scatter propagation is not a fixed value by the fading impact. It will change within a certain range. The prediction loss is the median of propagation loss in engineering. Scatter propagation algorithm prediction formula is:

$$A_s = A_m + 10\log d + 30\log\theta_0 + 30\log f + 20\log\left(5+\gamma H\right) + 4.343\gamma h_0 \qquad (6)$$

Where A_m is the meteorological factor, γ is the meteorological structure factor, d is the distance, θ_0 is the minimum scatter angle, H is the distance between the lowest point of the scatter body and the line connected transceiver, h_0 is the height of minimum scatter point, N_s is surface refractivity.

IV. SIMULATIONS

Based on the discussion of the previous theoretical analysis and prediction methods, some results of simulation will be given below. The input parameters of simulation are set like these. Communication frequency is from 400MHz to 20GHz. Communication distance is from almost 4000m to more than 300km. Each region studies two paths as the simulation results.

A. Simulation Result of Line-of-sight Propagation

In this line-of-sight region case, there are points A, B and C in Fig. 4 is shown on the left. Point A is transmitter whose antenna is 30m high in 32° 41' 46.3212" N and 118° 14' 36.3004" E. Point B is the receiver 1 whose antenna is 5m high in 32° 40' 31.0343" N and 118° 17' 17.6469" E. Point C is the receiver 2 whose antenna is 5m high in 32° 35' 3.1826" N and 118° 17' 33.5080" E. Two of communication lines AB and AC displayed in the topographic map from STRM-DEM plotted in Fig. 4 is shown on the left. The terrain profiles after curvature of Earth correction of AB and AC plotted in Fig. 4 is shown on the right.

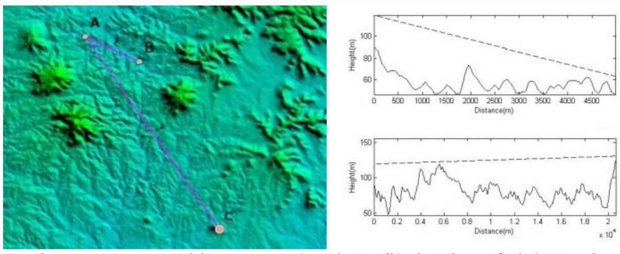


Figure 4 Topographic Maps and Path Profile in Line-of-sight Region..

The simulation uses the above line-of-sight propagation algorithm to predict and analyze two lines AB and AC. On the basis of the free space wave loss, it takes into account the diffraction loss and multipath loss caused by irregular surface. Multipath loss is a fast fading which loss values change over time. It is percentage of time selected to represent in the case. The percentage P means the percentage of time when loss beyond the loss value we calculate. P is from 0.1 to 50. Meanwhile, the loss is heavily dependent on the impact of regional environments, researches use the surface reflection coefficient N to characterize. N is equal to 301 in continental temperate climate conditons. The simulation result of line-of-sight propagation is shown in Fig. 5. Above one is path AB and below one is path AC. It can be seen form the simulation results that the impact of different percentage of time decreases with the increase of communication distance.

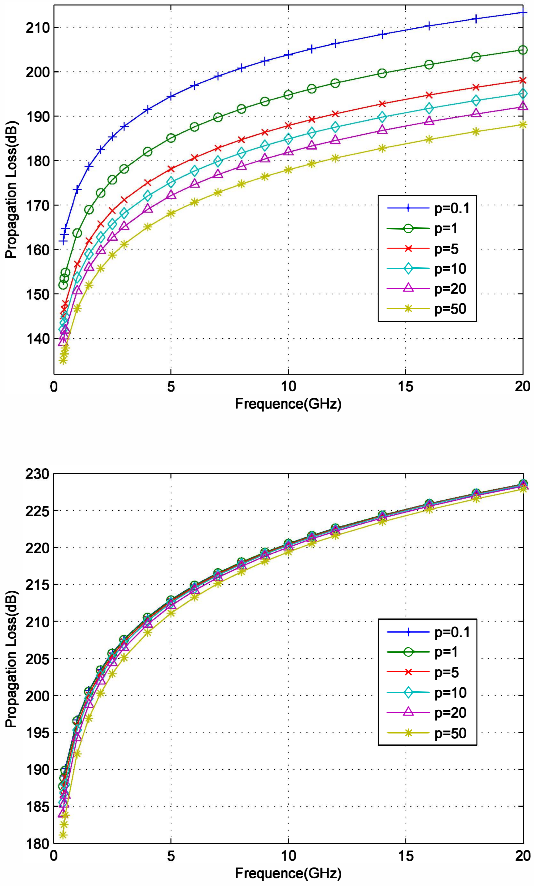


Figure 5 Propagation Loss of Line-of-sight Lines AB and AC..

B. Simulation Result of Diffraction Propagation

In this diffraction region case, there are points A, B and C in Fig. 6 is shown on the left. Point A is transmitter whose antenna is 20m high in 31° 07 ' 58.8449" N and 117° 29' 13.5395" E. Point B is the receiver 1 whose antenna is 5m high in 31° 24' 5.5775" N and 117° 23' 26.8513" E. Point C is the receiver 2 whose antenna is5m high in 30° 52' 57.2593" N and 117° 29' 51.1055" E. Two of communication lines AB and AC displayed in the topographic map from STRM-DEM plotted in Fig. 6 is shown on the left. The terrain profile after curvature of Earth correction of AB and AC plotted in Fig. 6 is shown on the right.

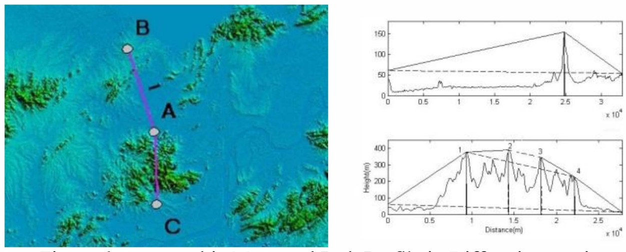


Figure 6 Topographic Maps and Path Profile in Diffraction Region..

The simulation uses the above diffraction propagation algorithm to predict and analyze two lines AB and AC. On the basis of the free space wave loss, it mainly considers the impact of tall peaks block the horizon line. The simulation result of line-of-sight propagation is shown in Fig. 7. Above one is path AB and below one is path AC. Path AB is a single peak diffraction type. More complex situation path AC is a four peaks diffraction type. It can be seen form the simulation results that propagation loss increases rapidly with the increase in the number of peaks.

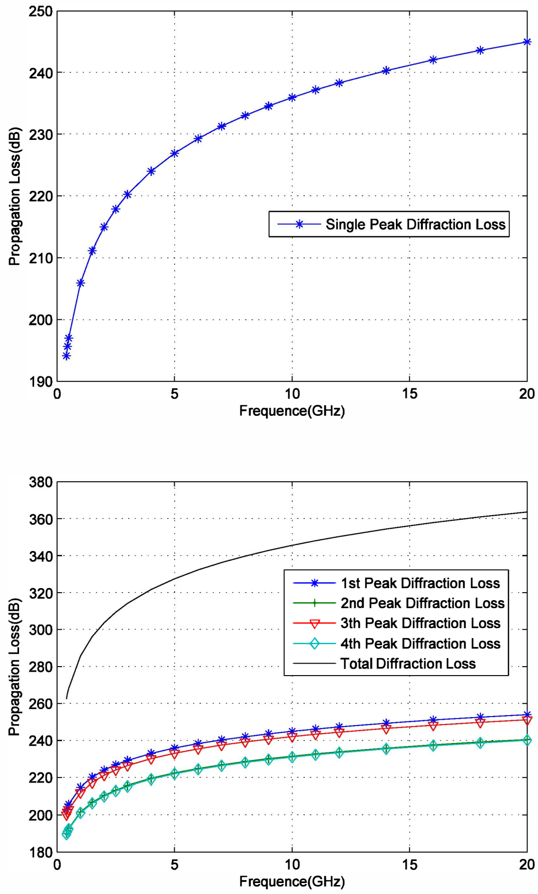


Figure 7 Propagation Loss of Diffraction Lines AB and AC..

C. Simulation Result of Scatter Propagation

In this scatter region case, there are points A, B and C in Fig. 8 is shown on the left. Point A is transmitter whose antenna is 20m high in 30° 59' 31.4824" N and 119° 10' 26.8382" E. Point B is the receiver 1 whose antenna is 5m high in 33° 18' 10.2966" N and 117° 04' 37.6780" E. Point C is the receiver 2 whose antenna is 5m high in 31° 00' 48.087" N and 117° 14' 4.2845" E. Two of communication lines AB and AC displayed in the topographic map from STRM-DEM plotted in Fig. 8 is shown on the left. The terrain profile after curvature of Earth correction of AB and AC plotted in Figure 8 is shown on the right.

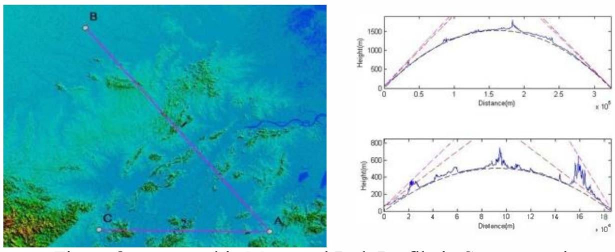
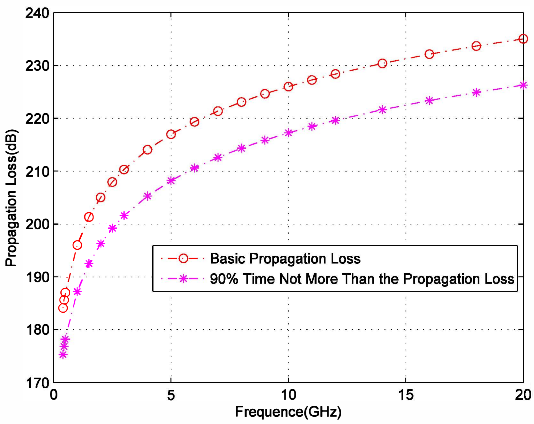


Figure 8 Topographic Maps and Path Profile in Scatter Region.

The simulation uses the above scatter propagation algorithm to predict and analyze two lines AB and AC. Due to the long distance in the scatter region the radius of the Earth has a great impact on terrain profile. Over-the-horizon scatter propagation loss prediction considers the meteorological parameters and the parameters about public scattering body volume and height. On the basis of the basic propagation loss, it considers the time shift factor which indicts that the propagation loss in 90% of the time is not exceeded. The simulation result of line-of-sight propagation is shown in Fig. 9. Above one is path AB and below one is path AC.



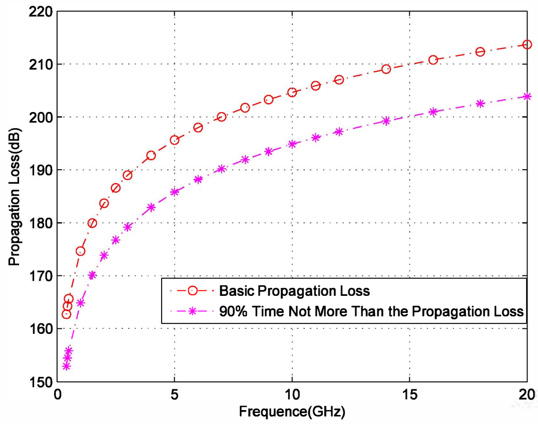


Figure 9 Propagation Loss of Scatter Lines AB and AC..

V. CONCLUSIONS

In this paper, characteristic prediction of radio wave propagation loss based on complex irregular terrain of wide-range distance has been studied and simulated. A fast and accurate path loss prediction method is put forward in engineering applications. The simulation results prove that the prediction method is valid within the frequency range from 400MHz to 20GHz.

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