TELKOMNIKA, Vol. 11, No. 7, July 2013, pp. 3834 ~ 3840
e-ISSN: 2087-278X

Research on Hybrid Ray-tracing at 2.4 GHz in Man-Made Forests

Yun-jie Xu*, Wen-bin Li
School of technology,Beijing Forestry University, Bei jing, China
Fax: +86 01062338139
*Corresponding author, e-mail: leewb@bjfu.edu.cn

Abstract

The shadow of diffraction, which account for the growth of trees based on wireless sensors and automatic acquisition of environmental information, were presented to meet the requirements for a wireless sensor network in a forest. there's a necessity to avoid the dead zone of signal diffraction when laying wireless sensor in the forest, the integration of SBR and UTD is applied to study the impact of 2.4GHz radio-frequency signal on the path loss characteristics in the forest. Shadow fading is studied by considering random variations of trees height and position. Path loss to subscribers located in a forest are found using refraction and diffraction concepts. This paper achieved the ray location from the receive pint to field point by using back-ray tracing method and computed the response electric field relative to each ray by using UTD. This article presents an overview of popular prediction models and describes electric field algorithms that are based on the authors' experience, to improve their accuracy. Take the poplar planted forest for instance. The measured value and simulated value were compared, finding good consistency between them, which indicates that SBR and UTD can effectively predict the path loss characteristics in the forest.

Keywords*: man-made forests, Inverse Ray-tracing, standing tree, 2.4 GHz*

1. Introduction

Ray tracing's primary benefit is that it is relatively straightforward to compute shadows and reflections. In addition, ray tracing is well suited to "walkthroughs" of extremely large models due to advanced ray tracing's low asymptotic time complexity which makes up for the required preprocessing of the model.

Numerous propagation models for microcells are based on a ray-optic theory. In comparison with the case of macro cells, the prediction of microcell coverage based on the ray-model is more accurate. One of the elementary models is the two-ray model. The two-ray model [1] is used for modeling of the Loss radio channel. Also, there are more complex models based on the ray-optic theory. The four ray model consists of a direct ray, ground-reflected ray, and two rays reflected by buildings. The six-ray model, besides the direct and the ground-reflected ray, takes four rays reflected by the building walls along the street. If a model considers a larger number of rays, the prediction tends to be more accurate, but the computational time is significantly increased. The problem deserving special attention is that of the corner diffraction. Two popular models considering this effect are the GTD (Geometrical Theory of Diffraction) model [2], and the UTD (Uniform Theory of Diffraction) model [3].

But, when compared the 2GHz signal propagation problem with these applied ray tracing techniques, regardless their common points, we still identified the following main difference, geometrical optics almost gives no consideration to the wedge diffraction which, however, plays an important role in UHF as its existence enables the field to reach to the deep shadow zone that is impossible in geometrical optics. Reflection in geometrical optics mainly focuses on diffusion while in UHF, it is the direct reflection that in domination. Of course, the difference between wireless transmission and visibility decreases with the increase of frequency.

Given the abovementioned differences, it is impossible to apply the existing visible ray tracing techniques to solve the signal propagation in UHF directly. Therefore, it is necessary to

Received January 30, 2013; Revised April 20, 2013; Accepted May 8, 2013

carry out a detail study on the transmission mode of electromagnetic wave in the planted forest in order to achieve a thorough research on the transmission law of UHF in it.

2. Signal Scanning Algorithm in the Forest

Ray tracing requires detail site information of specific environment. The transmission mechanisms of electromagnetic wave in space are mainly collineation, reflection, diffraction and transmission. As far as the absorbing screen environment of UHF is concerned, as the tree trunk is non-transparent, we can only give consideration to the following four situations: collineation, locality principle-consistent reflection, diffraction as well as the combination of reflection and diffraction, neglecting the impact of transmission. Path loss to subscribers located in a forest are found using refraction and diffraction concepts. The model is shown in figure 1. To model the effect of trees, we make use of the physical optics approximation. Next will be discussed separately for receiver points of sensors.

1) Well inside the illuminated region before first diffraction point (1,2,…,8) ,that is visible, The model is shown in figure 2 .

2) Well inside the shadow region after first diffraction point (1,2,…,8) , that is invisible.

3) In a transition region about the shadow boundary .

UHF electromagnetic wave propagation in the absorbing screen shows obvious damping, making it possible to neglect secondary or multiple reflection, diffraction as well as their combination.

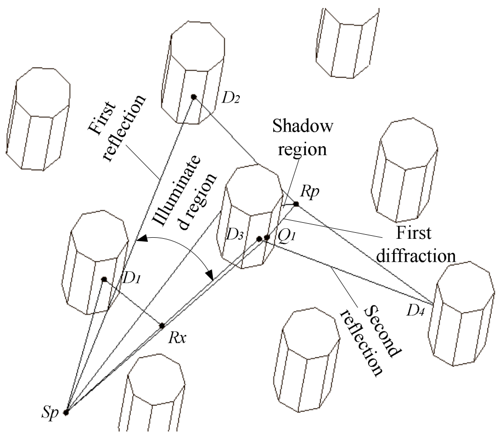

Figure 1. The standing tree 3D modeling map of once horizontal scanning

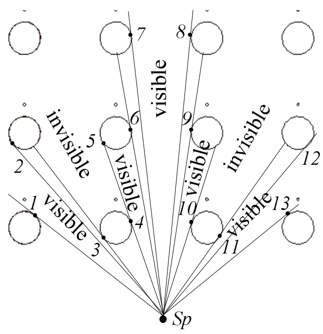

Figure 2. The visible zones of once diffraction

According to the characteristic of signal wave polarization in the forest, we first apply the horizontal scanning algorithm here and give no consideration to the tree height for temporary. Before the horizontal search, the table of visible wedge including emission source point, receiving field point, all wedge diffraction points, etc. shall be established and all possible paths from receiving field point to emission source point shall be determined, which will be combined with the information storage of stumpage model to accomplish the ray horizontal scanning. The source point in information storage of the stumpage model equals to the origin of coordinates of the rectangular coordinate system, field point equals to the receiving point, and diffraction point equals to the intersection point of edges and scanning line. The visible surface of source point and field point shall be determined in advance since we have to consider once diffraction as well as once reflection.

2.1. Once Diffraction Scanning

Take the stumpage arrangement method of row 3 and line 3 for example. As shown in Figure1, from which we can see that the base point Sp and receiving point Rx can only be reached through diffraction. First, determine the scanning base point Sp and then draw out the tangential line of all visible columnar, obtaining 13 scanning contact points shown in figure 2. Those cross the contact points belong to the vertical curves of the columnar, or known as vertical wedge. Simplify the stumpage based on the initial edge whose prism is the tangential line. Finally, examine and compute all scanning lines within the scanning zone according to certain order. The connecting line between base point Sp and contact point is the scanning line. Divide the space into two zones according to the situation of scanning line and cylindrical surface tangency: visible zone and invisible zone. Viewed from figure 2, the 13 scanning contact points divided the space into three visible zones and 2 invisible zones. List the three visible zones obtained through once diffraction, shown in table1.

Table 1. The visible zones table of once diffraction

sourc e point	visib le zones 1	visible zones 2	visible zones 3
1	Sp-1-2-3	Sp-4-5-6-7-8-9-10	Sp-11-12-13

The simplified model of once diffraction space of standing trees is shown in figure 3. Simplified model of once diffraction space. Where Sp is source point, Rx is receiver point, Q is diffraction point.

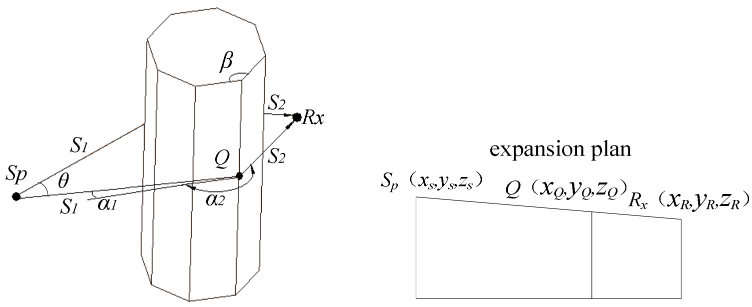

Figure 3. The simplified model of once diffraction

There are the specific solution can be used to solve the diffraction points when the receiving point Rx is known, the procedure is as follows [6]:

1) Establish the visible zone table of once diffraction and determine the common visible wedge of emission point and field point;

2) After finish the layout of emission point and sensor nodes, the coordinates of source point and field point can be known. Choose one common visible wedge and calculate the diffraction point value through the equation set 1.

3) Develop the incidence face and diffraction face in one flat surface along the vertical surface line of column which locates in the diffraction point Q, results shown in Figure 3. Calculate the coordinate of diffraction point z in right-angled trapezoid, and $Z_Q = Z_R + |Z|$.

$$|Z| = \frac{\sqrt{(x_Q - x_R)^2 + (y_Q - y_R)^2}}{\sqrt{(x_Q - x_R)^2 + (y_Q - y_R)^2} + \sqrt{(x_S - x_Q)^2 + (y_S - y_Q)^2}}(z_S - z_R) \qquad (1)$$

4) Effectiveness judgment. After the diffraction point is obtained, it needs to determine whether the diffraction point lies in the finite-length vertical wedge. If zQ≤H1, the diffraction path exists; otherwise, no diffraction path exists.

5) Repeat the above steps and choose the common visible vertical wedges of other living woods until all the common visible wedges are calculated.

2.2. Once Reflection Scanning

In the UHF, reflecting is a localized phenomenon, according to the principle of locality for solving the structure of the reflected field of mainly focused on solving the reflection point. Viewed from figure 3, reference to the specific solution of the diffraction points, the specific solution can be used to solve the reflection points is as follows:

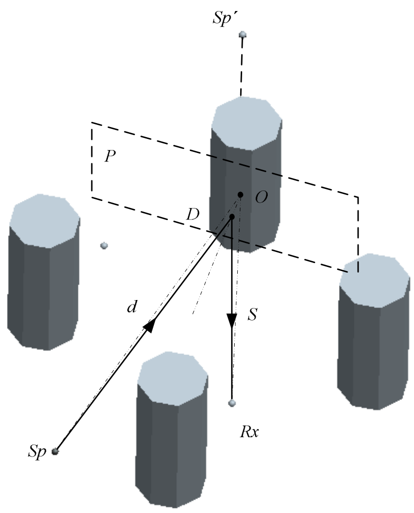

Figure 4. First reflection tracking

1) Establish the visible zone table of once reflection and determine the common visible wedge of emission point and field point;

2) The connection source point Sp, center O and field point Rx of reflected standing tree, solving angle bisector for linear OSp and linear ORx , as shown in figure 4;

3) Solving this angle bisector vertical and the cylindrical tangent to a plane P, this plane is the only, P is the reflection plane;

4) the reflection plane P the mirror points obtained source point Sp mirror point on P S'p;

5) connected to the mirror point and field point Rx, the intersection is the reflection point D of this line and a plane.

6) Effectiveness judgment. Two conditions: □ Reflection point in the image point and source point between; □ reflection point to belong to the reflecting surface P.

7) If the reflection point is valid, then the connection of SpD and the DRx, to judge of SpD and DRx whether the other plane, a sharp split intersect. If no intersect occurred this reflection path exist.

8) Repeat the above steps and choose the common visible vertical wedges of other living woods until all the common visible wedges are calculated.

3. Field Strength of Standing Tree

After the spatial path of ray is determined, the vector computation can be carried out by disintegrate them into scalars. According to the early researches, it is possible to implement vector computation for the field strength of signals represented by rays to obtain the field strength of receiving signals.

Considering the deflection of polarization vector brought by reflection and diffraction, this paper computes the polar component of receiving wave in the basic coordinate system of ray. The following formula is applied to compute the electric field that reaches receiving antenna.

The end field strength of direct is:

$$E(L) = E_0 \frac{e^{jkS_1}}{S} \tag{2}$$

The field strength of the diffraction field that is S away from the diffraction field point Q is[6]:

$$E^n(Q) = E^{n-1}(Q) D(\theta) A(s) \exp(-jks \sin\gamma) \exp(-jkz \cos\gamma) \tag{3}$$

exp(-jkzcosγ) is phase delay factor.

In the radio wave propagation environment in the forest, all simplified diffraction wedges are medium wedges of limited conductivity, which requires to calculating its diffraction coefficient $\bar{D}$.

$$D = \frac{-\exp\left[-j(\frac{\pi}{4})\right]}{2n\sqrt{2\pi k}\sin\beta}\left[\cot\left(\frac{\pi+(\alpha_1 - \alpha')}{2n}\right)F\left[kL\alpha^-(\alpha_1 - \alpha')\right] + \cot\left(\frac{\pi-(\alpha_1 - \alpha')}{2n}\right)F\left[kL\alpha^-(\alpha_1 - \alpha')\right] + R_0\cot\left(\frac{\pi+(\alpha_1 + \alpha')}{2n}\right)F\left[kL\alpha^+(\alpha_1 + \alpha')\right] + R_n\cot\left(\frac{\pi-(\alpha_1 + \alpha')}{2n}\right)F\left[kL\alpha^+(\alpha_1 + \alpha')\right]\right] \tag{4}$$

R0 is the reflection coefficient of 0 face, Rn is the reflec-tion coefficient of face, $n\pi - \alpha_2$ angle of incidence.

Where , F(x)is the transition functions, and is given by

$$F(x) = \frac{1+j}{2}\sqrt{2\pi x}\exp(jx) - 2j\sqrt{x}\int_0^{\sqrt{x}}\exp(-j\tau^2)d\tau \tag{5}$$

L is the parameter of distance, and is given by

$$L = s \cdot \sin^2(\frac{\theta}{2} - \frac{2\pi}{n}) \tag{6}$$

S1 is incident wave process, S3 is reflected wave process. α_1 is angle of incidence, ε is the complex permittivity, $\varepsilon = \varepsilon_r - j60\sigma\lambda$ is the relative dielectric constant.

The field strength of the reflection field that is S away from the reflection field point Rx is:

$$E(Rx) = E(S)RA(s)e^{-jks} \tag{7}$$

The reflection coefficient R is expressed as:

$$R = \begin{pmatrix} R_{//} & 0 \\ 0 & R_{\perp} \end{pmatrix} \tag{8}$$

$$R_{\parallel} = \frac{\varepsilon \cdot \left|(\overline{n_b}, \overline{d})\right| - \sqrt{\varepsilon - 1 + (\overline{n_b}, \overline{d})^2}}{\varepsilon \cdot \left|(\overline{n_b}, \overline{d})\right| + \sqrt{\varepsilon - 1 + (\overline{n_b}, \overline{d})^2}} \tag{9}$$

$$R_{\perp} = \frac{\left|(\overline{n_b}, \overline{d})\right| - \sqrt{\varepsilon - 1 + (\overline{n_b}, \overline{d})^2}}{\left|(\overline{n_b}, \overline{d})\right| + \sqrt{\varepsilon - 1 + (\overline{n_b}, \overline{d})^2}} \tag{10}$$

$R_{\perp}$, $R_{\parallel}$ is Vertical polarization and parallel polarization of the reflection coefficient. The total electric field strength of the receiving point is:

$$E_{\text{total}} = n\sum_{\text{i}=1} E_{\text{i}} \tag{11}$$

The total path loss is:

$$P_{\text{total}} = 20\log\left|\frac{\lambda}{4\pi}\frac{E_{total}}{E_0}\right| \tag{12}$$

4. Study on the 2.4GHz Path Loss Character-istics

First, study the contribution of ray to the strength of receiving signals. Choose the planted poplar forest as the main sampling tree. Just as shown in Figure 5, collineation and reflection play the dominate role in signal receiving in illumination zone while the diffraction signal plays the most critical role in transition zone.

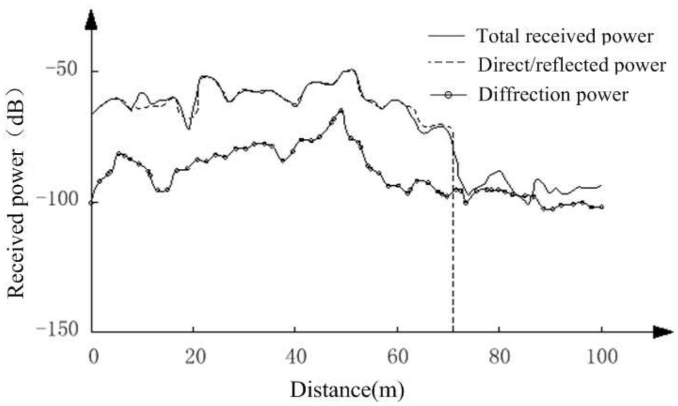

Figure 5. Contributions to the received signals

Figure 2 is the simulated zone and the area lies behind the shadow border is transition and invisible zone. Micaz integrated node module is applied for emission and field intensity indicator is applied for receiving. From Figure 6, we can see good consistency between the measured value and simulated value, which indicates that in 2.4GHz frequency, the ray tracing method is able to effectively predict the path loss characteristics in the planted forest environment. Furthermore, the predicted values of path loss on the test point are generally smaller that the measured values, which is caused by the simplification of planted forest environment and living woods during simulation as well as the error of propagation model. For example, the simulated value neglects the impact of secondary or multiple diffraction and reflection.

5 Conclusion

Using a ray-tracing method based on shooting and bouncing (SBR)/uniform theory of diffraction (UTD), this paper mainly analyzed how the Once diffraction scanning and Once diffraction scanning influenced the path loss respectively. The integration of SBR and UTD is applied to study the impact of 2.4GHz radio-frequency signal on the path loss characteristics in the forest. The feasibility and validity of computing the Inverse Ray-tracing of standing tree in plantation is verified using theoretical analysis and simulation. Finally, the results between the forecasts and measurements are presented. And the predicted results are in good agreement with the measured one, which shows that this kind of ray tracing method can efficiently predict the propagation characteristics.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China (Grant No. 30972425) and the Natural Science Foundation of Zhejiang Province of China (Grant No. LY12C16003). Corresponding author: Wen-bin Li.

REFERENCES

[1] HH Xia et al. "Radio Propagation Characteristics for Line-of-Sight Microcellular and Personal Communication". *IEEE Trans. Ant. and Prop*. 1993: 41.
[2] RJ Luebbers. "Finite Conductivity Uniform GTD Versus Knife-edge Diffraction in Prediction of Propagation Path Loss". *IEEE Trans. Ant. Prop*. 1984; 32: 70-72.
[3] RG Kouyoumijan and PH Pathak. "*A Uniform Theory of Diffraction for an Edge in a Perfectly Conducting Surface*". Proc. IEEE. 1974; 62: 1448-61.
[4] JHW hltteker. Frresnel-Kirchhoff theory applied to terrain diffraction problems. *Radio Sci*. 1990; 25: 837-851.
[5] YJ Xu, WB Li. Propagation path loss prediction model of multi-sensor network in forest. *Procedia Engineering*. 2011; 15: 412-414.
[6] YJ Xu, WB Li. Hybrid Path Algorithms of Inverse Ray-tracing at UHF in a man-made forests. *International journal of advancements in computing technology*. 2011; 15: 412-414.
[7] MG Wang. *Geometrical Theory of Diffraction*. China Xidian University Press, Beijing. 1989.
[8] X Wen, YX Xie. Diffraction over a Flat-Topped Terrain Obstacle with Bevel Edge. *Chinese Journal of Electronics*. 1995; 23: 81-83.
[9] YJ Xu, WB Li. *Strength Prediction of Propagation loss in Forest Based on Genetic-SVM Classifier*. 2010 Second International Conference on Future Computer and Communication. 2010; 03: 251-254.
[10] Henry L Bertoni. Radio propagation for modern wireless system. *Publishing House of Electronics industry*. Beijing. 2002.
[11] BG Lee and Wan YC. “Multi-Targets 3D Indoor Navigation on PDA with Wireless Sensor Network”. *Sensor Letters*. 2011; 09: 234-242.
[12] LI WB, ZHANG JM, SA C. “WANG DM, GAO K. Model for forecasting the electric field intensity of UHF wireless frequency band in forests”. *Journal of Beijing Forestry University*. 2007; 29: 15-18.