The study of wireless signal propagation characteristics under micro-cellular environment

Yucheng Zhang[1, 2]*, Fangtao Yu[2]

[1] *Department of Electronic Information Engineering, Xijing University, Xi'an 710123, China*

[2] *Xi'an Aeroengine Controls Corporation, Aviation Industry Corporation of China, Xi'an 710072, China*

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Abstract

A wireless signal automatic tracking model is established aiming at radio wave propagation characteristics of micro-cellular environment, which is based on ray-tracing theory and MATLAB simulation, using the method of radiation source tree. Firstly, reflection and diffraction point set are judged theoretically. Secondly, the wireless signal path tracking algorithm is proposed. In order to validate correctness and rationality of the algorithm, the simulated calculations combined with the urban environment of Ottawa are employed; at the same time, the wave propagation path is given and the optimal combination is chosen. Finally, the simulation and calculation results are analyzed and compared, thus the optimum model are obtained. The results show that the algorithm has higher precision and comparatively accurate forecasting results; what's more, it has the significant reference value for the propagation prediction of the cellular radio and the construction of the base station.

Keywords: Signal tracking, Microcellular, Reflection, Diffraction, Simulation

1 Introduction

As the mobile communication technology goes increasingly deeper, in order to make full use of existing resources and increase the network capacity to improve the ability of mobile communication, the system of microcell and micro-microcell is widely used. The base stations based on this system are usually set up on the top of all kinds of communities, which need an effective prediction of signal intensity in the communities through the radio wave propagation models, but the cover sizes and buildings are not all the same in different communities, so the traditional forecast models based on measuring fail. How to effectively predict the loss of wireless signal propagation has very important meaning for network planning and design. In recent years, the growing research on radio wave propagation characteristics has been concentrated on the study of microcell propagation characteristics, and achieved good results. For instant, in the literature [1-3], the ray tracing model based on high frequency of electromagnetic hypothesis is able to accurately consider various propagation effects of electromagnetic wave and various factors which influence the radio wave propagation.

Accordingly, a lot of ray information that includes propagation path, time delay, angle of arrival and angle of departure, as well as field information and capacity information are obtained under the microcellular scenario. The empirical model proposed in literature [4-6] has been used to microcell in practical engineering design. In this article, ray tracing method based on reflection, diffraction, projection and scattering phenomenon of electromagnetic wave is used, and it can simulate propagation of the electrical beam with the help of the computer to determine the path of the electromagnetic wave and propagation characteristics in the urban environment, so it has certain economic benefits and strong practicability.

2 Ray-tracing algorithm

Aiming at the ray path tracing model, transmitter can be as a radiation source tree root, and rays start from the source point, they will be reflected when meet with the surface of buildings, but diffracted when meet with the vertex of buildings. In the situation of diffraction, the ray will become the new emission source [7], this sub sources propagate piece by piece in the same radiation pattern, and the energy is reduced at the same time, until it reaches the maximum number of iterations or the radio wave energy is used up, the radio wave propagation will stop. As shown in figure 1 that is the iteration tree of radio wave propagation path way.

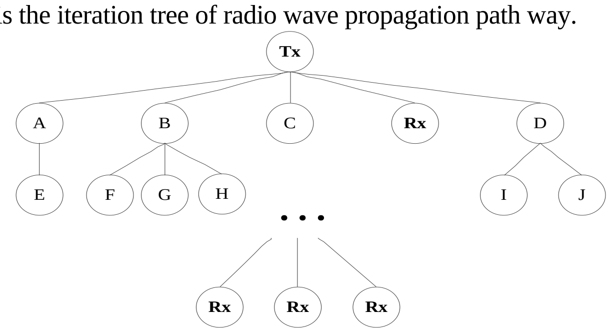

FIGURE 1 The tree demo figure of ray tracing model

2.1 REFLECTION POINT SET JUDGMENT MODEL

Occlusion judgment is an important part of the ray tracing model, and how to make the accurate and calculable occlusion judgment is the key to the problem [8]. Figure 2 is discriminant model sketch of the reflection points set. It starts from the starting point and finds the next reflection points set of Tx which belongs to the starting point.

* ***Corresponding author*** e-mail: zyc123098@126.com

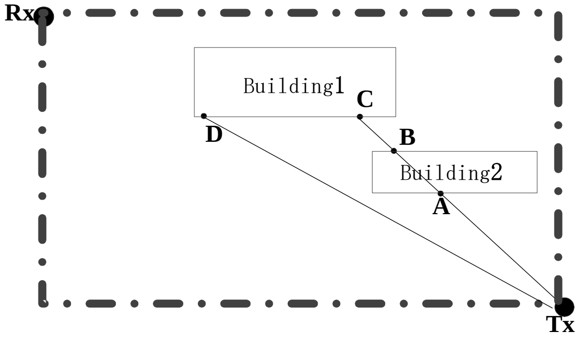

FIGURE 2 Discriminant model sketch of the reflection points set

$$\begin{cases} x \in Rset(\mathrm{Tx}), & \text{if } \mathrm{xTx} \times \mathrm{eb} = 0 \\ x \notin \mathrm{Rset}(\mathrm{Tx}), & \text{if } \mathrm{xTx} \times \mathrm{eb} \neq 0 \end{cases}. \quad (1)$$

In the equation (1), x shows all the points on the edge of the buildings except vertexes, and eb shows the other sides of the buildings except the sides which include the studying points. Rset(Tx) shows the next reflection points set of Tx which belongs to the starting point, xTx shows the line segment from point x to the starting point Tx.

Model interpretation: when the line segment from point x of the buildings to the starting point Tx and the other sides of the buildings except the sides which include point x have no intersections, there will put this point in to the reflection points set of Tx, as the next reflection or diffraction sub sources. As shown in figure 2, the line between A and Tx as well as the line between D and Tx have no intersections with the other sides of the No.1 building and No.2 building except the sides which include point A and point D, so point A and point D will be put in to the reflection points set of Tx. But the line between C and Tx has intersections with two sides of the No.2 building, so point C will be not put in to the reflection points set of Tx.

2.2 DIFFRACTION POINT SET JUDGMENT MODEL

Diffraction is another way of radio wave propagation. Diffraction is a phenomenon that electromagnetic wave will change the direction of propagation, when the radio wave is kept out by bigger size obstruction which compared with wavelength. In the process of diffraction propagation, when the incident ray irradiates on the vertex of the building in any angle, the diffracted ray will propagate in any exit angle to the area that has no buildings coverage. In this paper, there suppose the corners of the wall are all right angles, so the effective range of the diffraction source is $3\Pi/2$, Figure 3 is a sketch of the diffraction source scope.

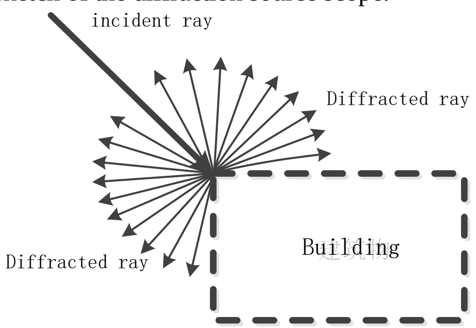

FIGURE 3 The sketch of the diffraction point propagation

Firstly, as shown in figure 4(a), case 1, which is the judgment of diffraction point set has been given. The judgment standard for all the diffraction points of Tx on the sides which don't parallel with v is to check whether the line between the starting point Tx and the vertex has another intersection with all the sides except the sides which include the studying points. If there has another intersection, the point will not be the diffraction point of Tx. For example, point B is chosen as the object of study, TxB has only one intersection B with the edge vector AB, so point B is the diffraction point of Tx, but for point A, TxA has another intersection C besides intersection A with the edge vector BA, so point A is not the diffraction point of Tx.

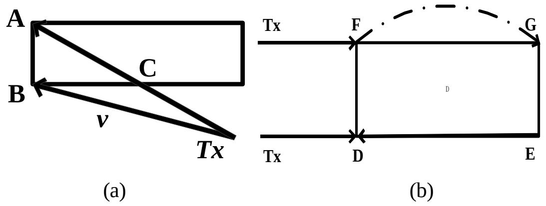

FIGURE 4 The diffraction point set judgment schema of the starting point Tx

Secondly, as shown in figure 4(b), case 2 is to determine whether point D is the diffraction point of the starting point Tx. Taking point D as the object of study, if (D-Tx)* (D-E)<0, point D will be elected to the diffraction point set of Tx.

Finally, as shown in figure 4(b), case 3 is to determine whether point G is the diffraction point of the starting point Tx. If (F-Tx)* (G-F)>0, point G will be not to elected to the diffraction point set of Tx. In figure 4(b), the dotted line between point G and point F is called virtual line, it's drawn so as to understand easily.

According to the case 1, we can summarize the diffraction point set judgment model 1:

$$\begin{cases} y \in Dset(Tx), & \text{if } (y - Tx) \times eb = 0 \\ y \notin Dset(Tx), & \text{if } (y - Tx) \times eb \neq 0 \end{cases}. \quad (2)$$

According to the case 2 and case 3, we can summarize the diffraction point set judgment model 2:

$$\begin{cases} y \in Dset(Tx), & \text{if } (y - Tx) \times (y - z) < 0 \\ y \notin Dset(Tx), & \text{if } (y - Tx) \times (y - z) > 0 \end{cases}. \quad (3)$$

In the equation (2) and (3), y shows all the vertexes on the edge of the buildings, Tx represents the starting point, Dset(Tx) represents the diffraction point set of Tx, point z represents the vertex on the same side with point y, eb represents the other sides of the buildings except the sides which include the studying points.

2.3 THE PATH FOLLOWING ALGORITHM MODELING

In this section, combined with relevant evidence of the reflection point set judgment model and the diffraction point set judgment model, the path following algorithm modeling has been given, and it's schematic diagram as shown in figure 5.

Step1: Tx is taken as the starting point, and all the diffraction point set of Tx are selected on the basis of the diffraction point set judgment model. Then, judge the reflection point set from the remaining nodes. In figure 5, j represents the number of diffraction, i represents the number of reflection, and A represents each maximum number of the upper limit.

Step2: Look for the concentrated elements in the new diffraction point set and the new reflection point set one by one, and see if it exists the points which can reach the Rx, if it exists, all coordinate values of the new diffraction points and reflection points will be recorded in the roadSet, and enter Step4, otherwise, it will enter Step3.

Step3: Traverse the next elements of Rset and Dset, and choose the element as the new starting point. Then, Step1 and Step2 will be repeated.

Step4: Connect all the points which have been saved in the roadSet in sequence, the paths will be obtained from the starting point Tx to the receiving points via many times of diffraction and reflection. Because of energy loss in the process of the radio wave propagation, energy will be attenuated negligibly after many times of diffraction and reflection. In this paper, the condition we only consider is that the number of diffraction is not more than two times and the number of reflection is not more than seven times.

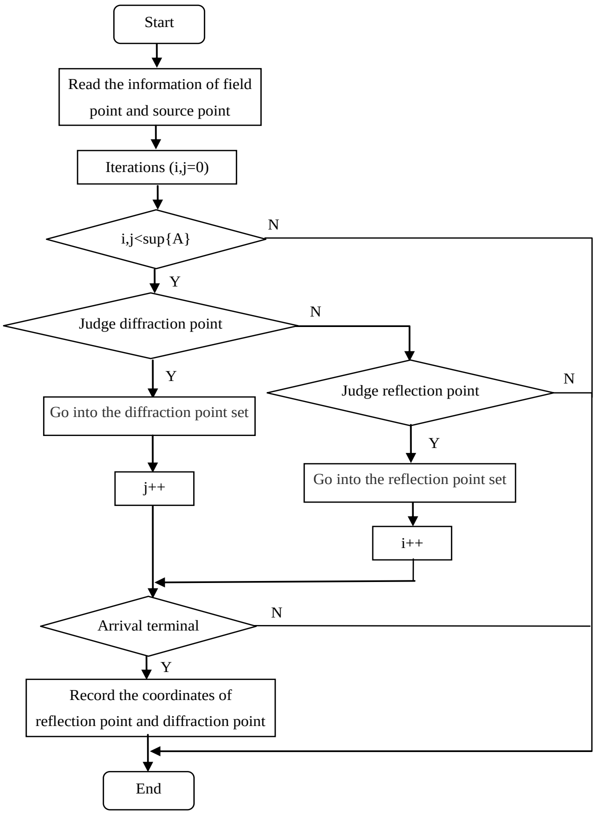

FIGURE 5 The schematic diagram of the path following algorithm

3 Simulating calculation of the model

Using the model established in this paper to do simulating calculation for the downtown environment of Ottawa. As shown in figure 6, it's a simplified urban plan. In figure 6, Tx is the transmitter which coordinate is (500,200), and Rx is the receiver which coordinate is (250,350). The questions are set as follows.

(1) Do simulation about the main propagation path between the transmitter Tx and the receiver Rx.

(2) Take five points with the interval of 50m to place the transmitter on the path of AB, and the coordinates of point A and point B are (300,350) and (500,350) respectively. Take five points with the interval of 25m to place the receiver on the path of CD, and the coordinates of point C and point D are (450,300) and (450,200) respectively. Thus, there will be 25 kinds of transmitter and receiver combinations, we have to find the best and the worst transceiver combinations.

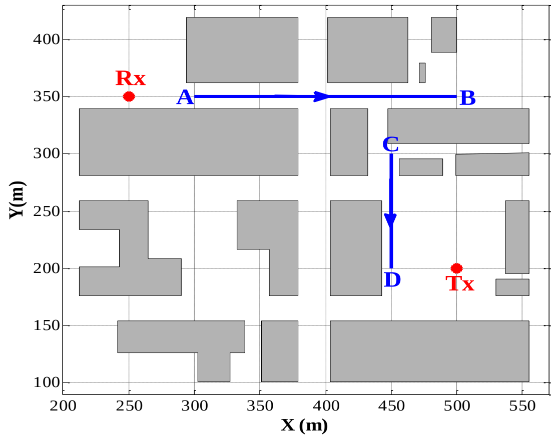

FIGURE 6 Part of Ottawa Downtown 2D view

According to the ray tracing algorithm, we have used MATLAB to simulate the results of path tracking from the starting point Tx to the ending point Rx. As shown in figure 7 and figure 8, there are schematic diagrams of simulation for question 1 and question 2.

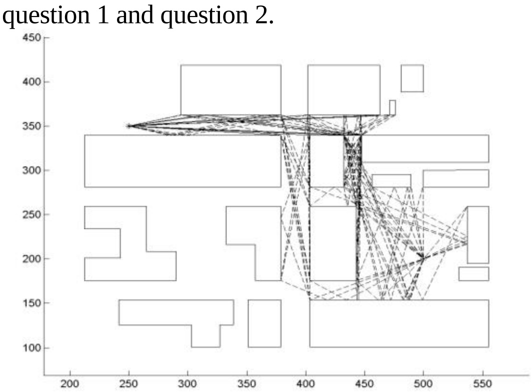

FIGURE 7 The schematic diagram of path tracking for question 1

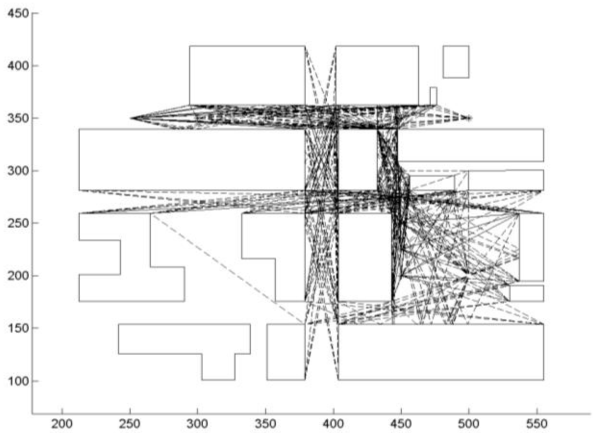

FIGURE 8 The schematic diagram of path tracking for question 2

3 Analysis of simulation result

We have studied the propagation paths of 25 kinds of transceiver combinations and used the computer simulating calculation to get statistical table of the effective ways for every combination, as shown in table 1.

TABLE 1 The total paths of all transceiver combinations

	***Rx*1**	***Rx*2**	***Rx*3**	***Rx*4**	***Rx*5**
Tx 1	77	109	71	66	51
Tx 2	66	104	62	61	50
Tx 3	150	312	194	213	214
Tx 4	175	253	198	196	183
Tx 5	67	97	61	58	45

The five transceivers points Tx (300:50:500,350) are used Tx1- Tx5 to express respectively, and the five receivers points Rx(450,300:-25:200) are used Rx1- Rx5 to express respectively.

From the table 1, we can see that the combination which coordinates of Tx and Rx are (500,350) and (450,200) respectively is the worst combination in all the combinations, and it only has 45 effective paths. But the combination which coordinates of Tx and Rx are (400,350) and (450,275) respectively is the best combination in all the combinations, and it has 312 effective paths. Then, the transmitter and the receiver features of the best combination have been analysed, as shown in table 2 and table 3.

As shown in table 2, there is a statistical analysis about transmitter Tx which coordinate is (400,350), different receiver positions and different propagation limiting modes. Parts of the modes are given in table 2, d represents diffraction and r represents reflection in this table.

TABLE 2 Different receiver paths analysis of Tx(400,350)

Mode	**r2d1r2**	**r1d2**	**r1d1**	**d2r1**	**d2**	**d1r1**
R1	9	19	1	72	23	3
R2	9	54	4	109	85	6
R3	8	28	1	99	36	3
R4	8	26	1	120	35	5
R5	10	22	0	130	29	5
Sum	44	149	7	530	208	22

Therefore, for the launching point Tx (400,350), the mode d2r1 has got the most effective paths after two times of diffraction and one reflection, and it has 530 effective paths. What's more, the worst mode is r1d1. Then, the receiving points are analyzed.

TABLE 3 Different receiver paths analysis of Rx(450,275)

Mode	**r2d1r2**	**r2d1**	**r1d2**	**d2r1**	**d2**	**d1r1d1**
T1	2	1	14	41	23	1
T2	28	10	72	60	37	2
T3	9	4	54	109	85	3
T4	4	1	16	41	23	1
T5	1	1	23	41	23	1
Sum	44	17	179	292	191	8

For the receiving point Rx(450,275), the mode d2r1 has got the most effective paths after two times of diffraction and one reflection, and it has 292 effective paths. What's more, the worst mode is d1r1d1.

As shown in figure 9 and figure 10, there are the statistics about the total effective paths of launching point and receiving point. By comparison, for the launching points, Tx which coordinate is (400,350) can send the most effective signals and form 1083 effective paths, and they are received by every receiving point. For the receiving points, Rx which coordinate is (450,275) can receive the most effective signals from every launchingpoint and form 875 effective paths. Further analysis found that the two positions are both on the road intersections near the setting range of launching and receiving points in the community.

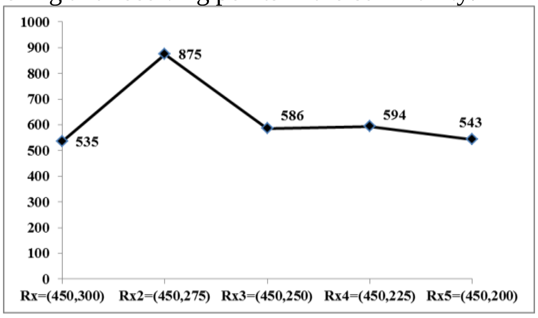

FIGURE 9 Statistics about the effective paths of every receiving point (unit: pieces)

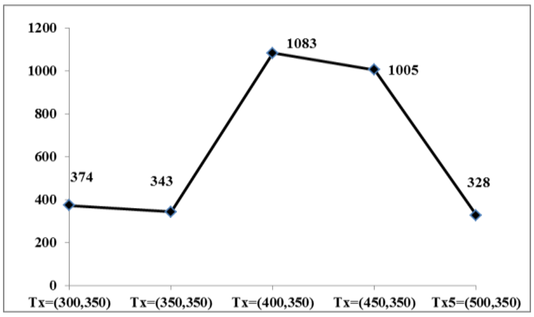

FIGURE 10 Statistics about the effective paths of every launching point (unit: pieces)

In conclusion, according to the result of test data, we can find that the combination which coordinates of Tx and Rx are (400,350) and (450,275) respectively is the most efficient launching and receiving combination. At the same, we also find that the most efficient launching point is Tx which coordinate is (400,350) and the best receiving point is Rx which coordinate is (450,275). On the selection of propagation modes, the mode d2r1 is always the most effective way whether launching points or receiving points, but the mode d1r1 and d1r1d1 are both the worst selection modes whether launching points or receiving points. It has a certain technical guidance significance with these rules for the people who work on network business of the wireless communication, meanwhile, it can bring some help for the people's daily life and promote people to exchange information and study efficiently and quickly.

4 Conclusions

In this paper, the method of radiation source tree is based on the theory of mirror image in essence, it's a kind of point to point tracking method, and you can find all the radio waves propagation paths from the transmitter to the receiver with high precision. The method is combined with the decision algorithms of reflection points and diffraction points, and it uses the method of ray tracing to follow the tracks of the wireless signal. We assume that the transmission environment is quasi-three dimensional in this paper, but because tall buildings are dense under the urban environment and the height of the base station antennas are lower than surrounding buildings, the three dimensional problem can be changed into two-dimensional problem, and the two-dimensional ray tracing model has been established in this paper and the model has been simulated with MATLAB to verify the effectiveness, and the results show that it has very high practical value for cellular radio waves propagation prediction.

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Authors

Zhang Yucheng, 1978.03, Xi'an City, Shaanxi Province, P.R. China

Current position, grades: the Lecturer of School of Electronic Information Engineering, Xijing University, China.
University studies: received his B.Sc. in Computer Science and Technology from Xidian University University of ShanXi in China.
He received his M.Sc. from Xi'an University of Science And Technology in China.
Scientific interest: His research interest fields include Computer Network , Embedded System
Publications: more than 5 papers published in various journals.
Experience: Natural Science Research Project of Educational Committee (2013JK887).

Yu Fangtao, 1978.06, Xi'an City, Shaanxi Province, P.R. China

Current position: the Engineer of Xi'an Aeroengine Controls Corporation, Aviation Industry Corporation of China, Xi'an, China.
University studies: received his B.Sc. in Computer Science and Technology from Xidian University University of ShanXi in China.
He received his M.Sc. from Xi'an University of Architecture and Technology in China.
Scientific interest: His research interest fields include Electronic communication, Computer simulation
Publications: more than 6 papers published in various journals.
Experience: Natural Science Research Project of Educational Committee (2013JK887).