Implementation and Validation of a 2.5D Intelligent Ray Launching Algorithm for Large Urban Scenarios

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***Abstract*—This paper presents a modified ray launching model based on the Intelligent Ray Launching Algorithm (IRLA) that was previously proposed. IRLA is a 3D discrete ray launching model which can be used to predict urban and indoor coverage. However, the IRLA model suffers from high memory usage in large urban scenario with fine resolution. The modified propagation model requires less memory and runs faster than the IRLA model. The simulations are carried out and the performance is investigated. Experiments show that the modified propagation algorithm performs better than the IRLA model in large urban scenarios.**

I. Introduction

Nowadays, the propagation prediction has become an essential part in the process of wireless network planning and optimisation because it serves as the fundamental input. The propagation models consist of two kinds: large-scale and small-scale. The large-scale propagation models compute the variation of signal strength over large distances while the small-scale propagation models deal with the fading of the radiowave signal in the scale of a few wave-lengths, due to random effects, e.g. moving vehicles. Coverage predictions, as required by wireless network planning and optimisation process, can be obtained by large-scale propagation models.

State-of-the-art large-scale propagation models can be divided into three kinds: empirical, semi-empirical and deterministic models. Empirical models are based on a few parameters such as emitting frequency and/or the distance between the emitters and receivers. These models (such as Free Space, COST-231 HATA) are fast but they are inaccurate because they do not consider much of the environmental information. Empirical models are used for a quick overview of the coverage. Semi-empirical models improve the prediction accuracy by considering some of the environmental information. For example, COST-231 Multi-Wall model computes the path loss based on the material and the number of walls/floors between the emitter and the receiver. These models are fast enough to be handled by current PCs within a reasonable time scale and they offer higher accuracy than empirical models. Deterministic models are the most complex of the three. They offer the highest accuracy at the cost of computational complexity. They compute the signal attenuation based on the environmental information such as obstacles and their materials. Current existing deterministic approaches are normally based on two kinds: geometrical (such as ray-based) and physical (such as Finite-Difference-Time-Domain FDTD). Ray-based methods are based on simulating radiowave as rays. Rays are traced while they propagate and losses are computed based on each reflection, diffraction (e.g. via Uniform Theory of Diffraction UTD [1]), transmission or scattering. Generally, ray-based methods are composed of ray launching, ray tracing and dominant path. They differ in the ways on how they compute the rays. For example, ray launching computes the rays from the emitter while the ray tracing [2] computes the rays backwards from the emitter by mirroring. Ray launching is suitable for coverage prediction while ray tracing is more precise in point-to-point prediction. In spite of other previous efforts such as [3] and [4], they are still time-consuming in terms of computational complexity according to the current PCs' capability. For large urban scenarios, they usually require hours even days to obtain a coverage prediction. FDTD methods solve the Maxwell equation in a discrete grid. They consider inherently the ray phenomena (such as reflections and diffractions). Compared to ray-based methods, they are more accurate and yet they consume more memory and require more computational resources. Although many authors have proposed methods to accelerate FDTD such as [5], [6] and [7], the performance of FDTD is still limited and often they are used in small domains such as indoor and antenna design applications.

In [8] and [9], the authors have proposed an intelligent ray launching algorithm IRLA, which is a discrete 3D propagation method that can be used for urban and indoor scenarios. Unlike some ray tracing methods such as [3], the IRLA model does not require one-time preprocessing, which computes the visibility tree between objects and are used to accelerate computation during runtime. Acceleration techniques are proposed in [10], [11], [12] and [13]. The IRLA model has been validated by several scenarios such as COST231-Munich [14] and the results show that it is suitable for wireless network planning and optimisation since it provides accurate coverage prediction within a short time scale. However, the IRLA model is built on a discrete data set and therefore it suffers from high memory usage if a high resolution is used. This affects the prediction performance in terms of speed and accuracy. Especially, in large urban scenarios where a high resolution is used, the IRLA model may not be possible due to the high memory usage.

This paper contributes to reducing the memory usage of the IRLA model for large urban scenarios while it maintains a relatively high accuracy. The modified ray launching algorithm can be considered as the 2.5D version of the IRLA model. Simulations are carried out and the performance is investigated via the ChongQing scenario. Experiments show that the 2.5D IRLA model runs more efficiently than the IRLA model and the accuracy is maintained because the most dominant rays for urban scenarios are traced.

II. The 2.5D IRLA

The outdoor 3D IRLA model [8] consists of three main components: Line-of-Sight (LOS), Vertical Diffraction (VD) and Horizontal Reflection & Diffraction (HRD). The LOS component is responsible for computing the direct paths visible to the emitter and collecting the secondary cubes to launch reflections and/or diffractions. The HRD component recursively traces the rays until the signal strength falls below a threshold or the ray iteration has reached a limit. The VD component is based on a fast pixel checking procedure that computes the number of rooftop diffractions. Finally, the HRD component launches 3D rays that comprise of reflections and diffractions. This following will detail the modification of each component to 2.5D IRLA model and at the end the advantages and disadvantages of the modified model will be discussed.

A. LOS

The 3D IRLA model is based on a discrete data set with the size of (N_x, N_y, N_z), which represents the number of cubes for X, Y, and Z dimensions respectively. Therefore the total number of pixels obtained can be calculated as Equation (1).

$$N_{\text{total}} = N_x * N_y * N_z \tag{1}$$

The total number of discrete rays launched from the emitter to the cubes at the fringe is summed up in Equation (2) where $N_z > 1$.

$$N_{\text{rays}} = 2N_xN_y + 2(N_z - 2)(N_x + N_y - 2) \tag{2}$$

The modified IRLA model reduces the memory usage by only computing the ground-level pixels for urban scenarios.

The 2.5D IRLA model thus is built on a discrete data set with the size of $(N_x, N_y, 1)$, which reduces the third dimension to a constant. The storage of this dimension includes the clutter, the terrain and the discrete building information. Compared to the 3D IRLA model, the total number of pixels obtained in the modified IRLA model can be obtained by Equation (3).

$$N_{\text{total'}} = N_x * N_y \tag{3}$$

The rays are then simplified to 2D. Therefore the total number of discrete rays launched from emitter can be calculated by Equation (4) considering all 2D rays only i.e. the rays are launched from the emitter in the 2D plane to the cubes at the fringe.

$$N_{\text{rays'}} = 2(N_x + N_y) - 4 \tag{4}$$

Therefore, the modified IRLA launches fewer rays and thus is far more efficient than the full 3D IRLA model in urban scenarios.

B. HRD

The HRD component launches 3D discrete rays in the full 3D IRLA model. The computation for rays propagating is limited to 2D in the modified IRLA model. Meantime, the computation of the diffraction cone can thus be simplified in the 2D case. For example, the diffraction rays can be launched in the 2D plane instead of a full 3D cone as defined in Keller Cone [15].

C. VD

The VD component computes rooftop diffraction rays by launching $N_{\text{rays'}}$ scan-lines. In the 3D IRLA model, each scan-line has extended upwards which forms virtually a facet cut (to fill every pixel in 3D space). This has been eliminated in the modified model. Let us assume the complexity of calculation of each pixel is approximately average. Therefore the running time complexity of the VD component will be at least reduced from N_{total} to $N_{\text{total'}}$.

D. Clutter and Terrain

The clutter and terrain data is important for urban coverage prediction because they influence the signal propagation. A piece of clutter data refers to a material type (such as trees, river) that locates in the outdoor area. A piece of terrain data refers to the heights of the ground (altitudes). These two have a high impact on the radiowave propagation in the urban environment. For example, a hill will obstruct the radiowave propagation.

The usage of two such pieces of information in the IRLA model is made possible by integrating this information into the discrete data set. For example, the clutter data is integrated in cubic data bits [8] and treated as pass-by-attenuation [16]. The terrain data is built into the discrete data set in the 3D IRLA model by virtually adjusting the heights of buildings. This is simplified in the modified IRLA model by recording the altitude of each piece of ground. This piece of information is considered in the VD component. In the 3D IRLA model, the HRD component also considers altitude because this has been built into the discrete data set.

E. Calibration

In order to fit simulations to reality, parameters (such as materials) have to be tuned. For the 3D IRLA model, the 3D multipaths are computed for a predefined route of receivers and a simulated-annealing approach is conducted [8]. In the modified IRLA model, only the ground-level pixels can be computed for multipaths. The HRD component only computes 2D rays in the modified IRLA model, which slightly affects the calibration quality. However, this can be ignored since most dominant rays are over rooftops and the accuracy of the VD component does not degrade in the modified model.

F. Advantages and Disadvantages

The modified IRLA model thus consumes less memory and runs more efficiently, especially in multi-threaded simulations when more threads can be created due to a lower usage of memory for each thread. However, unlike the 3D IRLA model, only ground-level pixels are computed. The modified IRLA does not consider the terrain effects in the HRD model. This only affects the prediction accuracy to a small extent because for the urban scenarios the most dominant rays are over rooftops or other high obstacles such as hills. The prediction of such ray phenomena is considered in the VD component.

III. ChongQing Scenario

This section will briefly describe the outdoor scenario used to test the performance of the modified IRLA model. The city of ChongQing is considered as the most complex environment for radiowave propagation research in China because the city of ChongQing is built almost entirely on hills of different altitudes and meantime it has rivers and trees. It is usual that the altitude changes rapidly up to few hundred meters within a short distance.

Figure 1 shows the overview the ChongQing scenario (1775 buildings), which is around 42 km^2. The emitter is at the frequency of 2140 MHz (CW) and placed at the height of 85 meters on a building. The emitting power is 43 dBm. There are 9 drive tests (approximately 86,216 measurement points).

Figure 2 plots the clutter and terrain data of the ChongQing scenario. Each colour represents different clutter type. For example, the green denotes the greenland. It shows that the ChongQing scenario is abundant in clutter and the environment is complex in terms of terrain.

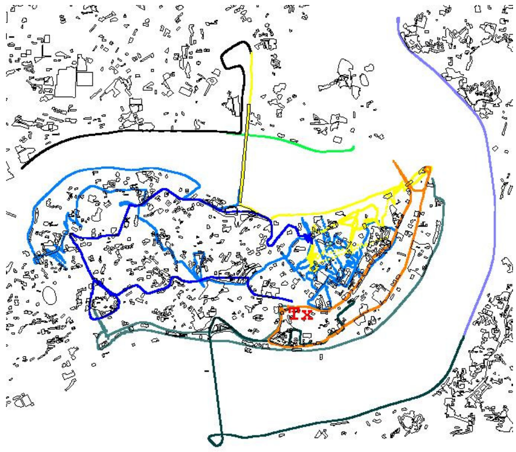

Fig. 1. The ChongQing Scenario, Red 'Tx' denotes the emitter and the coloured-lines are the measurement routes.

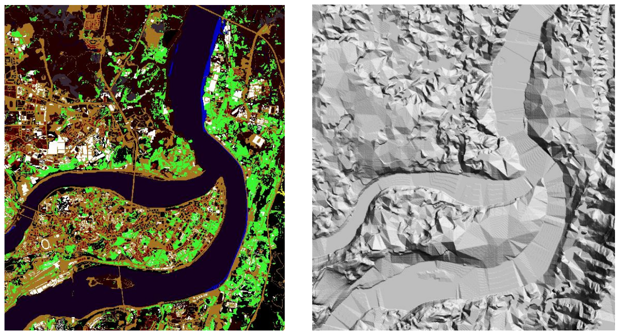

Fig. 2. Clutter and Terrain

IV. Results

A resolution of 5 x 5 x 5 meters is considered reasonable for a dense urban scenario. The number of reflections and diffractions are 5, 5 respectively. The size of the discrete grid is $(1201, 1401, 36)$ for X, Y and Z dimension respectively while in the modified IRLA model, the third dimension is reduced to 1. Therefore the summary of the memory usage for the discrete data set is given in Table I. It is observed that the modified IRLA model consumes far less memory than the 3D IRLA model and the creation of the discrete data set is more efficient. Besides, the discrete data set with a smaller size can usually be handled more efficiently due to cache techniques by standard PCs nowadays than with a larger size. Please be noted that both models are calibrated using the first measurement route.

A route of measurement points is selected as the calibration

TABLE I
Memory Usage Comparison on Intel T9400 Dual Core 4GB RAM, Vista

	IRLA	the modified model
Grid Size	1201 x 1401 x 36	1201 x 1401
Total	60573636	1682601
Creation Time (s)	59	5
Minimal Memory (MB)	231.07	6.42

TABLE II
RUNNING TIME (S)

	IRLA	the modified model
5 x 5 x 5	1193	93
3 x 3 x 3	–	332

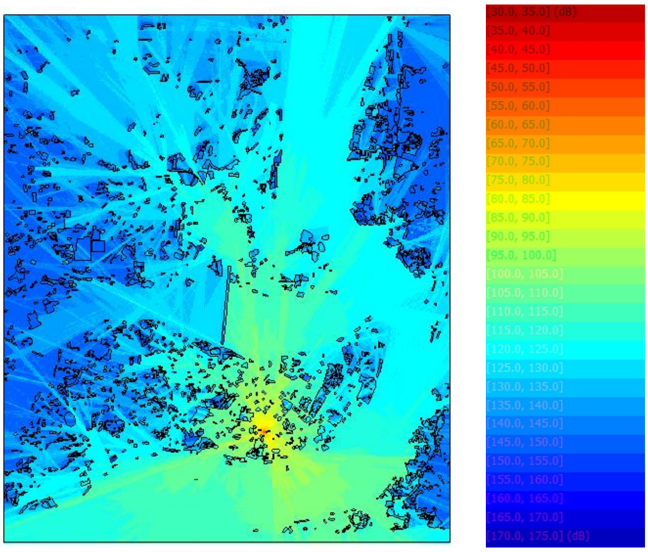

Fig. 3. Coverage Prediction by 2.5D IRLA (resolution of 5 x 5 m)

list. Based on the simulated annealing, the parameters are optimised. Table II shows the running time of two models with two different resolutions. It can be seen that the modified IRLA model runs faster because of a lower memory usage and less number of rays. It can be used to replace the full 3D IRLA model in the dense urban scenario when a high resolution is required i.e. in the full 3D model, the memory usage is high and makes the full 3D model less efficient.

The coverage prediction of the modified model is presented in Figure 3. Table III shows the accuracy for 9 measurement routes for the modified model. It shows that the simulation tends to agree well with the measurement. The accuracy (Root-Mean-Square-Error) for the comparisons are approximately within 8 dB. The comparisons between simulation and measurement can be found in Figure 5, 6, 7, 8, and 9 respectively.

Figure 4 plots multipaths computed in the 2.5D IRLA model between the emitter and a receiver. The multipaths are used to

TABLE III
ACCURACY COMPARISON ON INTEL T9400 DUAL CORE, 4GB RAM, VISTA. * - THE CALIBRATED ROUTE

	RMSE	Mean	Correlation (%)
Route 1 *	6.7	0.3	90.3
Route 2	6.8	-0.2	93.3
Route 3	7.3	0.13	92.3
Route 4	7.1	0.2	86.3
Route 5	8.1	0.01	85.1
Route 6	7.7	0.01	86.33
Route 7	7.9	-0.19	87.45
Route 8	7.29	0.01	88.3
Route 9	7.1	0.5	93.7

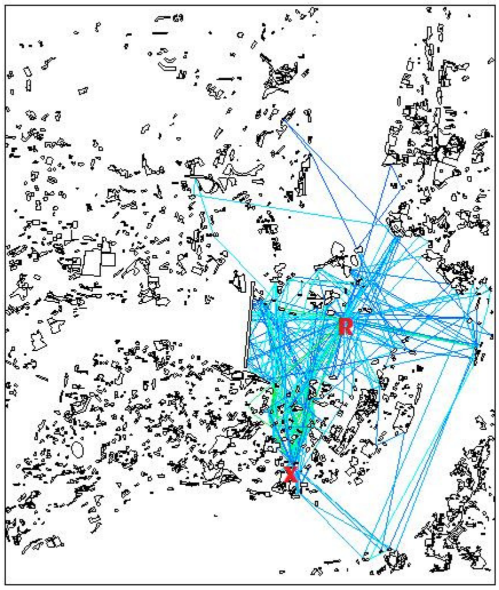

Fig. 4. Multipaths in ChongQing. X - Emitter, R - Receiver

compute the Power Delay Profile (PDP) and most importantly, are required for the calibration purpose. It is observed that the HRD component in the 2.5D IRLA model fails to predict the case that the signal strength can pass under the bridge where in 2D the bridge is treated as a blocking obstacle. However, the signal strength behind the bridge is compensated by the VD component that computes the contribution from the vertical diffractions.

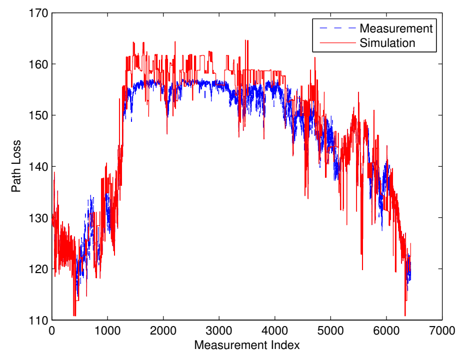

Fig. 5. Comparison of Route 1

V. CONCLUSION

This paper has presented an improved ray launching model based on the 3D IRLA model. The performance has been validated by the ChongQing scenario and it shows that the modified IRLA model consumes less memory and thus runs more efficiently in large urban scenarios.

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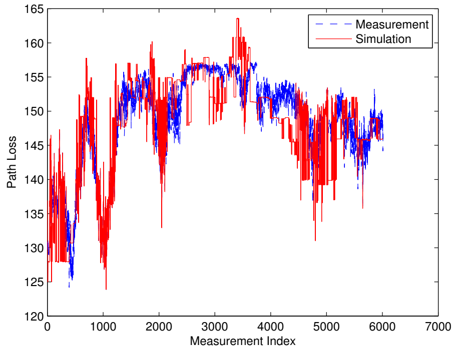

Fig. 6. Comparison of Route 3

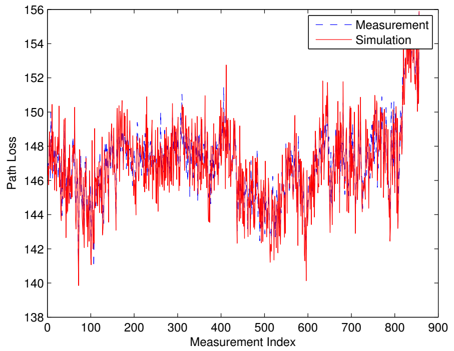

Fig. 7. Comparison of Route 5

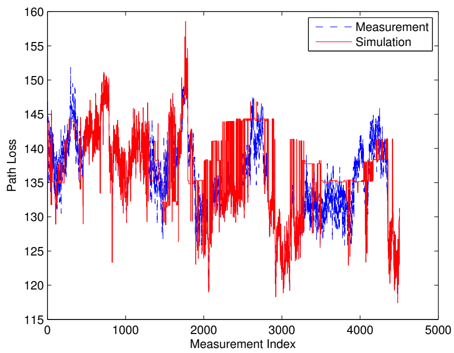

Fig. 8. Comparison of Route 7

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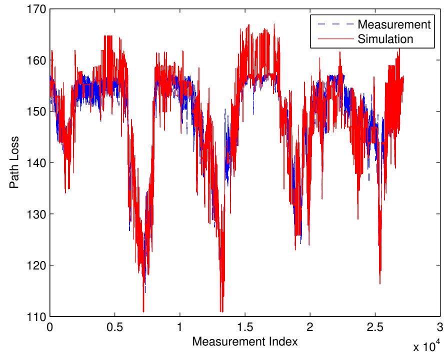

Fig. 9. Comparison of Route 9

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