Wide Area Ray-Launching for Pilot Pollution Analyses using Adaptive Object Selection

Yuma Matsuda, Hiroto Sugahara and Yasuhiko Matsunaga
System Platforms Research Laboratories, NEC Corporation.
1753, Shimonumabe, Nakahara-ku, Kawasaki, Kanagawa 211-8666, JAPAN
E-mail: y-matsuda@ew.jp.nec.com

Abstract: We propose a new method of ray-launching estimation for high-speed and highly accurate analysis of pilot pollution, which often occurs in the upper floors of high-rise buildings. Our method simulates radio signals that reach from distant base stations much faster than a conventional ray-launching method. The mechanism of the fast calculation is due to an adaptive object selection approach, which excludes objects that have limited effects on a radio environment in the upper floors of high-rise buildings. It is confirmed that our method can make a calculation more than 20 times faster than a conventional ray-launching method with almost the same accuracy for the case with high base station antennas.

1. Introduction

Pilot pollution is a problem in which no dominant pilot signals are received at the mobile terminal, resulting in an increase of interference level. This problem often occurs in the upper floors of high-rise buildings in which it is easy to satisfy the line-of-sight condition from a lot of distant base stations. Until now, various solutions have been proposed to mitigate the pilot pollution problem, such as optimizing the pilot power or the antenna configurations [1, 2]. However, there is little consideration of quantifying the geographical extent and seriousness of the problem, although this is necessary for deriving proper countermeasures. Measurement-based pilot pollution detection [3] is not always possible because of the cost and accessibility restrictions, especially inside buildings. As an alternative to the indoor field measurement, 3-dimensional (3D) radio propagation simulation is effective for pilot pollution detection. Ray-launching methods with 3D digital maps can estimate radio propagation by considering reflections and penetrations deterministically on the walls or roofs for each building, so that the estimation accuracy is high. However, long calculation time is required for the wide-area ray-launching simulation [4] which is indispensable for pilot pollution analysis in high-rise buildings.

To solve this problem, we propose a new method of ray-launching estimation that employs an adaptive object selection approach. With this method, we decrease the number of structured objects by excluding objects that have limited effect on the radio environment in the upper floors of high-rise buildings. In this paper, we describe the details of this method and evaluate its effect in terms of calculation time and estimation accuracy. We also discuss the applicability of the proposed method in various area categories and antenna heights.

2. Adaptive Object Selection Method

From the viewpoint of radio propagation simulation for the upper floors in high-rise buildings, we can categorize the simulation area into two areas. One is the area near the base station and the other is the area far from the base station, as shown in Fig. 1. To simulate the area near the base station, the reflection from the structured objects (buildings) far from the base station has little effect on the simulation results. Therefore, the number of structured objects is not so large, which leads to short calculation time. For example, our ray-launching simulator can simulate an area of 2x2 km^2 in less than 30 seconds per cell [4]. To the contrary, it requires long calculation time to simulate the area far from the base station because the number of structured objects becomes large. It is known that the calculation time increases rapidly as the number of structured objects increases [4].

To solve this problem, we employed an adaptive object selection method that excludes low-rise objects adaptively from the ray-launching simulation. If we consider the upper floors of high-rise objects, signals reflected by or penetrating low-rise objects may be blocked by high-rise buildings, and thus they will become much weaker than the direct signals from the base station. Therefore, such low-rise objects can be neglected when we run a ray-launching simulation. Moreover, since there are a large number of low-rise buildings or houses in an urban or a dense urban environment, we can expect a drastic decrease in the number of structured objects. The actual simulations were executed in the following two steps. We first excluded the objects if their heights were lower than the threshold as shown in Fig. 2. We then carried out ray-launching simulation with the remaining objects as shown in Fig. 3.

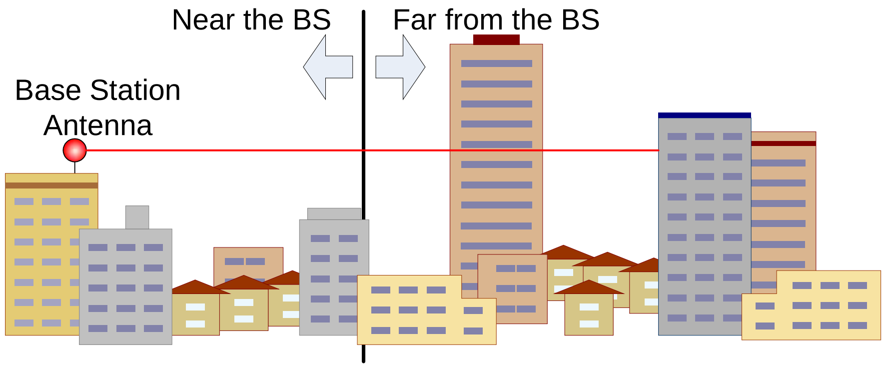


Figure 1: Categorizing Simulation Area into Two Sub-Areas

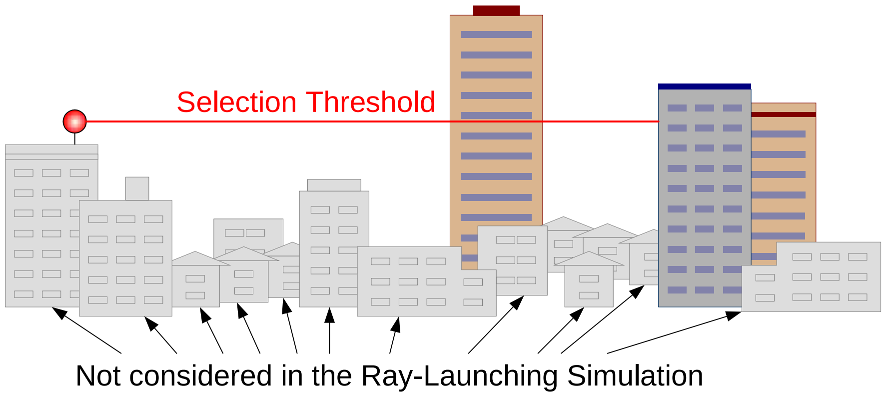
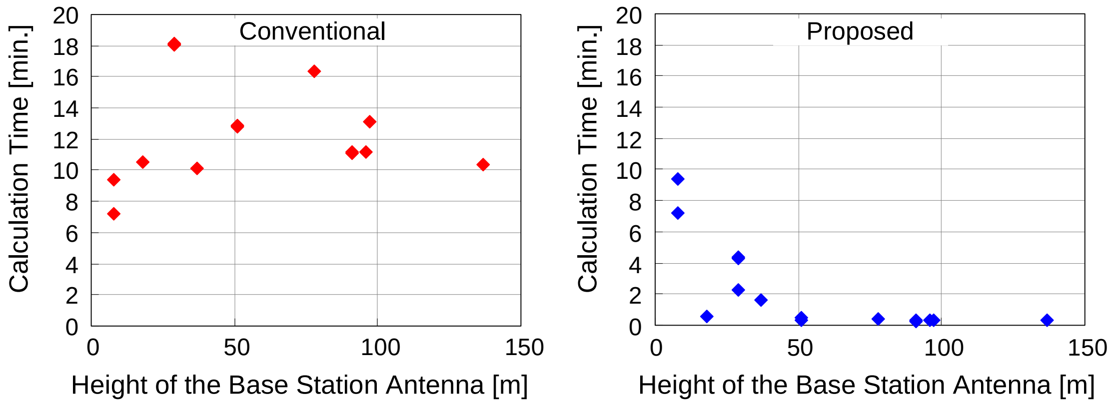


Figure 2: Adaptive Object Selection Method

3. Evaluation of Proposed Method

We evaluated the performance of our proposed estimation method in terms of calculation time in a 6x6 km^2 simulation area of the Kowloon peninsula and northern part of Hong Kong Island in Hong Kong. Our simulation hardware consisted of eight PC servers, each of which had a quad-core CPU of 2.1 GHz and a memory of 2 GB. The height threshold for object selection was set to be equal to the height of the base station antenna. The calculation times before and after applying the adaptive object selection method are shown in Fig. 3(a) and Fig. 3(b), respectively. The horizontal axis represents the height of the base station antenna, i.e. the object selection threshold. As shown in this figure, our proposed method significantly reduces the calculation time, especially when the height of the base station antenna is greater than 50 m. It took less than 30 seconds for our proposed method to make each simulation of a cell, whereas it took from 10 to 16 minutes for the conventional method. This corresponds to 20 to 32 times faster calculation for the base stations with high antennas. Note that the calculation time reduction is limited for the case with low base station antennas. In this case, however, signals are not likely to reach buildings far from the base station, so the calculation necessity can be limited.

To evaluate the estimation accuracy, we conducted field measurements of Received Signal Code Power (RSCP) of the Common Pilot Indication CHannel (CPICH) in a 3rd-generation commercial cellular network. Three high-rise buildings in the southern part of the Kowloon peninsula were selected for the field measurements. The measurement points were located on fortieth floor (an altitude of 165m), fifteenth floor (an altitude of 60 m), and fortieth floor (an altitude of 150 m) for each of the three buildings. All the measurements were carried out beside the window. Figure 4 shows the measured and estimated RSCPs. The horizontal axis represents the measured point number sorted in the order of the height of the base station antennas. Here, we compare the estimation results with the conventional ray-launching method and those with our proposed method. The mean absolute error for the proposed method was 4.2 dB, whereas that for the conventional method was 3.6 dB. Although the proposed method does not consider all objects inside the simulation area, the degradation of estimation accuracy was very small.



(a) Conventional Method (b) Proposed Method

Figure 3: Comparison of Calculation Time

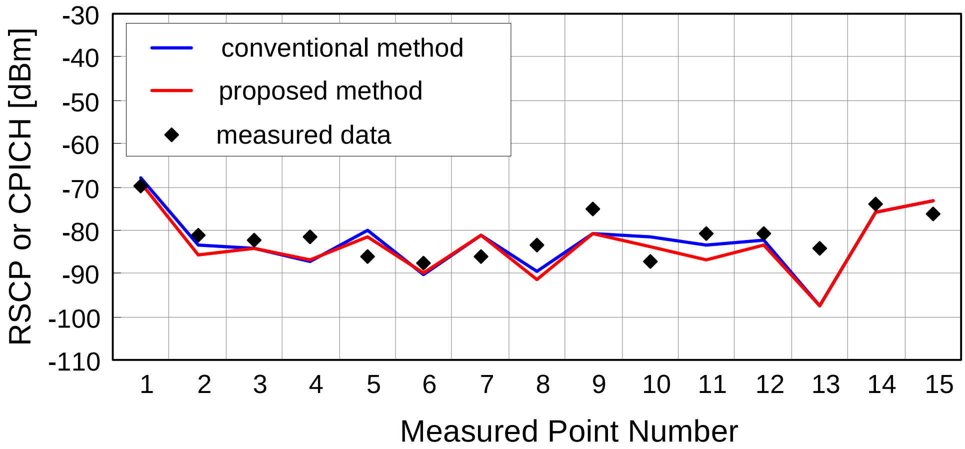


Figure 4: Comparison of Estimation Accuracy

4. Discussion

We discuss the applicability of the proposed method in various area categories and antenna heights in this section. The effectiveness of the proposed method is summarized in Table 1.

In an urban area, we have three categories according to antenna height. When the antenna height is high, such as on a tower, the size of the simulation area has to be large to simulate the wide coverage area, and therefore the number of structured objects in the simulation area is also large. On the contrary, the effect of the proposed object selection method is high, as discussed in the previous section. This enables the small calculation time, while it takes a long calculation time for a conventional method without using the adaptive object selection method. In the case of middle antenna height, in which the antenna is located on the rooftop of a building, the simulation area and the number of structured objects may be similar or smaller than the case with high antenna height.

Since a rooftop antenna is likely to be located on a relatively high building so as not to be blocked by the surrounding buildings, we can also obtain the high effect of the object selection. Thus, the calculation time can also be small.

For a street microcell, the signals may reach only the area along the street where the antenna is located. In such a situation, the number of structured objects can be small and therefore the calculation time is short. A similar manner can be used for a rural area. Although we need a large simulation area in this case, the calculation time can be originally short because there is a small number of objects. Therefore, we can run a simulation in a short time for any kind of area and antenna height by the proposed method.

Table 1: Comparison of effectiveness of proposed method and conventional method by area category and antenna height

Area Category		Urban			Rural
Antenna Height		High (Tower)	Middle (Rooftop)	Low (Street)	Any
1. Size of simulation area		Large	Large / Middle	Small	Large / Middle
2. Number of structured objects in simulation area		Large	Large / Middle	Small	Small
3. Object selection effect by proposed method		High	High	Low	Low
Calculation time	Conventional (1, 2)	Long	Long	Short	Short
	Proposed (1, 2, 3)	Short	Short	Short	Short

5. Conclusion

In this paper, we proposed an adaptive object selection method to significantly reduce the calculation time of wide area ray-launching simulation. This method excludes objects that have limited effects on the radio environment in the upper floors of high-rise buildings. We confirmed that our method can make a calculation more than 20 times faster than a conventional ray-launching method with almost the same accuracy for the case with high base station antennas. By using this method, we can estimate the complex radio environment inside the buildings in an urban area, which enables us to cope with the pilot pollution problem that often occurs in the upper floors of high-rise buildings.

References

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