Accuracy Improvement of Ray Tracing Method for Between 0.8 and 37 GHz in Street Cell Environment

Nobutaka Omaki, Tetsuro Imai, Koshiro Kitao, Yukihiko Okumura
5G Laboratory
NTT DOCOMO, INC.
Yokosuka, Japan
nobutaka.oomaki.wt@nttdocomo.com

***Abstract*—Recently, mobile networks employing high-speed high-capacity communications have been investigated extensively to satisfy the demand for the faster and larger data communication. As one of the approaches, frequencies between 6 and 100 GHz bands are the candidates to utilize the relatively wide frequency bandwidths. Accordingly, the characteristics of radio propagation loss in these frequency bands must be characterized. We investigate the characteristics of radio propagation loss in street cell environment in the frequency bands using Ray Tracing (RT) by comparing with measurement results. It was observed that RT calculation tends to exhibit estimation error as frequency increases. In this report, we propose to use alternative model with detailed building shape in intersection accounting for surface roughness. RT calculation with the proposed model is numerically evaluated to reveal the characteristics of path loss prediction. Finally, the proposed method is implemented to be compared with measurement results. Parameters of the proposed model are optimized and sufficient accuracy can be achieved in the frequencies between 0.8 and 37 GHz.**

Keywords—radio propagation; propagation loss; ray tracing; diffraction; surface roughness; 5G

I. INTRODUCTION

Recently, mobile networks employing high-speed high-capacity communications have been investigated extensively to satisfy the need for the higher and larger data communication beyond 2020 as the 5th generation (5G) mobile communication system. As one of the approaches to satisfy the needs, frequencies between 6 and 100 GHz are the candidates to utilize the relatively wide frequency bandwidths [1] for higher data rate. Accordingly, the characteristics of radio propagation loss in these frequency bands must be characterized. We have investigated accuracy of Ray Tracing (RT) simulation by comparing with measurement results and observed that the difference between RT simulation and measurement results tends to increase as frequency becomes large [2]. In this report, firstly, alternative model considering detailed shape of building in intersection as well as surface roughness is proposed. Secondary, The performance of RT simulation with the proposed model is numerically investigated in terms of shape of building and surface roughness. Finally, the proposed model with its shape and roughness is proposed by comparing with measurement results.

II. ANALYZED MODELS IN RT SIMULATION

It is stated earlier that conventional RT simulation method is not able to predict propagation loss accurately especially in higher frequencies and NLOS area away from intersection even though multiple paths are considered. In this section, conventional and proposed methods are described.

A. Conventional Method

Measurement result and RT simulation with the conventional method has been compared in the scenario of Fig. 1. Regarding conventional RT simulation method, the shape of buildings nearby intersection is assumed to be a wedge type model (*e.g.* Building II, III and IV in Fig. 1). The conventional wedge type models are assumed at the four corners of the intersection. RT simulation calculates wedge diffraction [3-5] to calculate field strengths as contribution of building. In general, all scattering objects are assumed smooth surface. Parameters of the measurement campaign is following; $W_{\mathrm{LOS}} = W_{\mathrm{NLOS}} = 32$ m, $\Delta w_{\mathrm{Rx}} = \Delta w_{\mathrm{Tx}} = 10$ m, and the heights of Tx and Rx are 10 and 2.5 m respectively. RMS error between measurement result and RT simulation is shown in Fig. 2 [2]. Here, it is observed that RT calculation tends to exhibit estimation error as the frequency increases.

B. Proposed Method

Fig. 3 shows some buildings near large intersections in the measurement site. It is noticed that building shapes in the large intersections seems barely like a conventional wedge shape. In order to correct the estimation error of RT calculation, we have focused on the building shape. Alternative model, namely, Rounded-Shape (RS) model has been proposed as Building I of Fig. 1 (a) [6]. RT simulation with RS model calculates specular reflection from curved surface [5,7] to estimate the field strength as a contribution of building while wedge diffraction with conventional wedge model. Fig. 4 illustrates different types of surfaces. Smooth surface should be a sufficient model when wavelength is large enough compared with roughness of scattering surface. On the other hand, surface should act like uneven or rough surface when wavelength is small. Reflected field may be rather scattered due to the surface roughness. Surface roughness is considered with surface roughness factor ρ [8]. Field attenuation due to surface roughness can be included in field calculation. In the proposed method, RS model with radius a and surface roughness parameter Δh is used as Building I while Building II – IV are remained to be conventional wedge shape model with smooth surface.

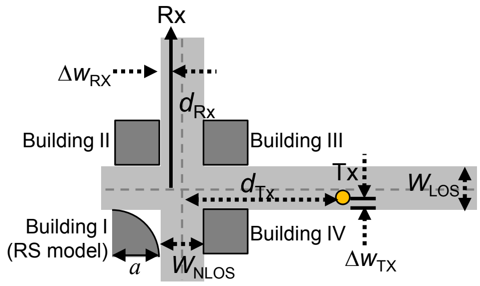


Fig. 1 Analyzed Model

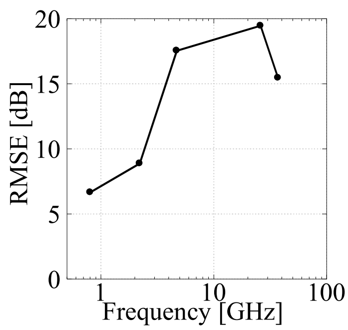


Fig. 2 Frequency dependency of the RMS error difference between RT simulation and measurement results. [2]

(a) Example 1 (Actual Building I)

(b) Example 2

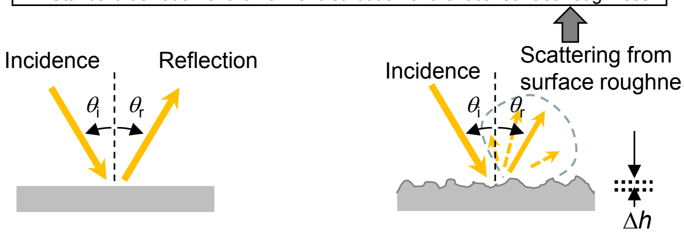
(c) Example 3

Fig. 3 Buildings in the measurement site

Surface roughness attenuation factor : $\rho = \sqrt{e^{-\left(\frac{4\pi\Delta h}{\lambda}\cos\theta_i\right)^2}}$

λ: Wavelength

Δh: Standard deviation of the normal distribution of the local surface roughness



(a) Smooth surface (b) Rough surface

Fig. 4 Different surfaces and scattering phenomena

III. Simulation Analysis

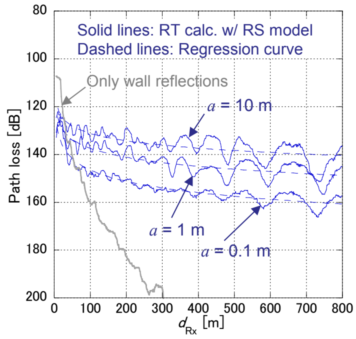
In this section, RT calculation with the proposed method is performed to numerically evaluate the characteristics of path loss estimation. Here, parameters of radius a and surface roughness Δh for RS model are variables. Five frequencies out of between 0.8 and 37 GHz are selected throughout this report.

A. Evaluation Method

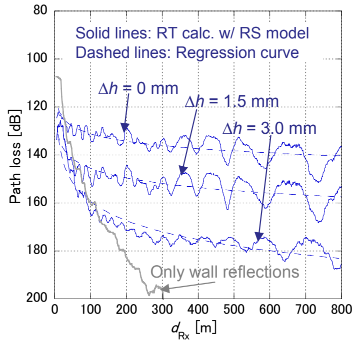
Fig. 1 shows analyzed scenario. These parameters are equivalent to the measurement scenario stated earlier chapter. Regarding RT simulation, both sides of the streets are assumed to be smooth surface of concrete (ε_r = 7, σ = 0.0023 S/m [9]). Multiple reflections of 10 are considered for LOS and NLOS route respectively. In order to evaluate the contribution only from building, the contribution of only wall reflections are not included in the calculation. Here, wall reflections indicate contribution of multiple reflected rays between side walls in the street. As evaluation scheme, regression analysis is performed for RT simulation result (distance dependency of path loss) so that the intercept m_0 and slope m_1 can be extracted based on logarithmic equation ($y = m_0 + m_1 \log_{10} d_{Rx}$). The propagation characteristics in terms of radius a (see Building I in Fig. 1) and surface roughness parameter Δh (see Fig. 4 (b)) can be finally evaluated by comparing these two parameters of m_0 and m_1 for different frequencies.

B. Evaluation of Building Shape and Surface Roughness

Fig. 5 shows path loss characteristics in terms of distance d_{Rx} at 37 GHz.



(a) Effect of radius a

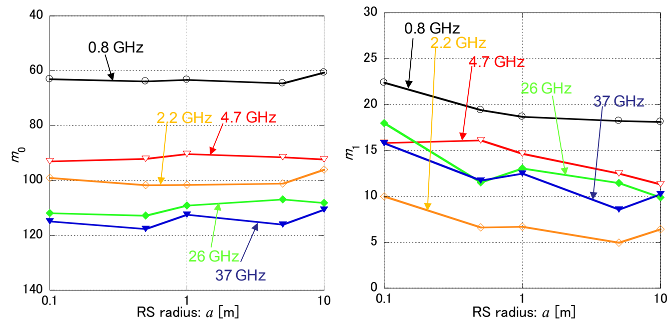


(b) The effect of surface roughness

Fig. 5 Path loss calculation at 37 GHz

Fig. 5 (a) shows path loss by RT calculation for different radius a of RS model. Here, smaller values of radius a predict larger path loss. Fig. 5 (b) also shows path loss calculation for different surface roughness Δh. Here, larger values of Δh predict larger path loss. Note the contribution of side wall reflections is also plotted ('only wall reflections'). The contribution is found to be larger up to d_{Rx} = 100 m at most than the results of RS model. Hence, main contribution should be realized to be scattering from buildings. Dashed curves of logarithmic regression for each simulation are also plotted so that the two parameters of intercept m_0 and slope m_1 can be extracted for each calculation.

Fig. 6 shows variation of intercept m_0 and slope m_1 for different values of radius a.

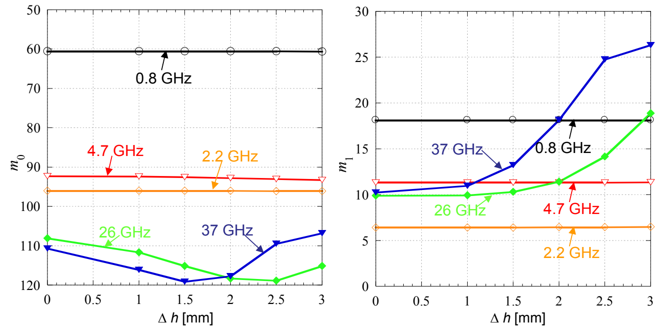


(a) Intercept: m_0 (b) Slope: m_1

Fig. 6 Effect of radius a

It is observed that intercept m_0 does not show clear variation as radius a increases for each frequency while slope m_1 decreases slightly when radius a increases.

Fig. 7 shows variation of intercept m_0 and slope m_1 for different surface roughness parameter Δh.



(a) Intercept: m_0 (b) Slope: m_1

Fig. 7 Effect of roughness

It is observed that both intercept m_0 and slope m_1 do not vary at low frequencies (0.8 - 4.4 GHz) while both vary at high frequencies (26 - 37 GHz). Larger values of Δh impact more on slope m_1 as frequency become higher. That is, path loss prediction is not affected by surface roughness with $\Delta h \leq 3$ mm when frequencies below 4.4 GHz.

IV. Comparison with Measurement Result

In this section, RT simulations with RS model for different values of radius a and roughness parameter Δh are implemented and compared with measurement result to optimize parameters for the proposed model.

Fig. 8 shows RMS error between measurement result and RT simulation with RS model for different values of radius a. Here, surface of RS model is assumed to be smooth. Different curves indicate different frequencies.

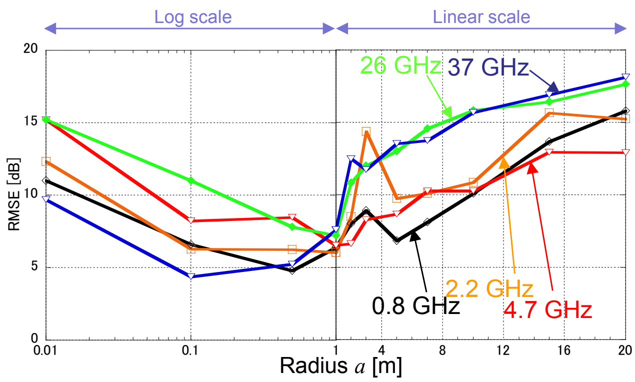


Fig. 8 RMSE: variation of radius a

Optimal radius is different for each frequency. No clear frequency dependency is observed either.

Fig. 9 shows RMS error between measurement results and RS model for different values of roughness parameter Δh. Here, radius a is fixed to be 7 m because the physical size of building in this specific measurement and route is about 7 m; Fig. 3 (a) is a picture of actual building located as Building I in this specific measurement.

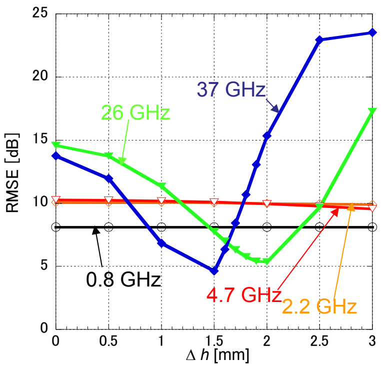


Fig. 9. RMSE: variation of Δh

It is found that RMSE is almost independent of the surface roughness parameters between Δh = 0 and 3 mm when low frequencies (between 0.8 and 4.7 GHz). On the other hand, RMSE at high frequencies (26 and 37 GHz) shows clear trend. Accuracy can be improved by utilizing Δh. For instance at 37 GHz, RMSE is improved from about 14 dB (smooth surface Δh = 0 mm) to 5 dB (rough surface Δh = 1.5 mm). Finally, RMSE can be minimized by optimizing parameters of radius a = 7 m and Δh = 1.5 mm for RS model, which is about less than 10 dB for all frequencies.

V. Conclusion

Large error exists in RT calculation with conventional wedge model in NLOS scenario of street cell environment. In order to improve the accuracy, alternative calculation method was proposed by using, namely, RS model accounting for detailed building shape as well as surface roughness.

Firstly, the impact of radius of the proposed RS model and surface roughness are numerically evaluated for different frequencies between 0.8 and 37 GHz. The size of radius altered the slope of distance dependency of path loss slightly. Roughness less than 3 mm did not impact on RT simulation result with RS model in the frequencies below 4.4 GHz. Finally, the error between measurement result and the proposed method was investigated to find out the optimal size of RS model and roughness. By utilizing parameters of RS model as physical building size (radius of 7 m) and roughness parameter of 1.5 mm, error was minimized to about 10 dB for all sampled frequencies, especially in high SHF and EHF bands.

In future, proposed method should be validated by comparing with other measurement results for general scenarios. Further improvement of low frequencies below 4.7 GHz should be considered for better path loss prediction in entire frequency bands.

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