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Prediction Model for the Estimation of Non-specular Wave Scattering Characteristics on Building Surfaces

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1 Introduction

Wave propagation prediction models are very crucial in determining propagation characteristics for any arbitrary installation on the implementation of mobile radio communication system [3]. The prediction models are required for proper coverage planning and the determination of multipath effects as well as interference. Our preceding researches [1][2] show that multipath propagation can be observed at many scatterers on the building surface roughness. The non-specular wave scattering from building surface is dominated more by vertical and horizontal frames of windows. The diffracted waves that correspond to Keller's law of diffraction can be investigated. Most of the arrival waves have a tendency to be distributed around the angle of specular direction. However, more scientific details are still required to understand the propagation phenomena.

This paper presents the development of simulation techniques for the estimation of non specular wave propagation characteristics on the building surface. Physical Optics (PO) approximation is performed to approximate equivalent currents and the total fields on the integration surface. A model of the rectangular microstrip array antenna was scanned spatially to detect multipath wave scattering. Superresolution method was also applied as an approach to handle signal parameters (DOA, TOA) of the individual incoming waves scattered from building surface roughness. The experimental and simulation results of the signal parameters of the arrival waves are compared in order to investigate accuracy of the prediction model.

2 Transmitter and Receiver Antennas Model

Following the propagation measurement of the experiment, a single rectangular and array microstrip antennas are applied in the transmitter and receiver antennas model, respectively. The patch size of the antenna model was 0.0179×0.0179 m^2 on a dielectric substrate with $\epsilon_r = 2.55$. The frequency of the antennas was 4.85 to 5.05 GHz. The wavelength was comparable with or smaller than the depth of the building surface roughness. The spatial scanning was configured to resemble an array antenna in the receiver antenna model. The spatial scanning was discretized for every 0.025 m toward the horizontal and vertical directions. The simulation was performed in the observation ranges of 0.5 m in the vertical and 8.125 m in the horizontal direction. The transmitter antenna is positioned facing towards the surface of the building. Figure 1 shows simulated antenna directivity of transmitter antenna for E-plane where they are compared with measurement result in anechoic chamber. A good agreement is indicated between predicted and measured results. Figure 2 shows top view of simulation arrangement. The spatial scanning model, transmitter antenna position, Line of Sight (LOS) direction and building surface shall also be presented.

3 Building Surface Profile

The profile of the building surface is shown in Fig. 3. The profile was taken from one of the buildings at Tokyo Institute of Technology. The surface of the building has non-uniformity due to the windows (glass), frames (aluminum), and walls (bricks). The surface has periodical irregularity of five periods. One period of the surface equals 3.7 m. The windows are made up of the sidewall, aluminum frames and plain glasses, which in principle are the building roughness, as well as the wall surface. The dimensions of the window's glasses of the building

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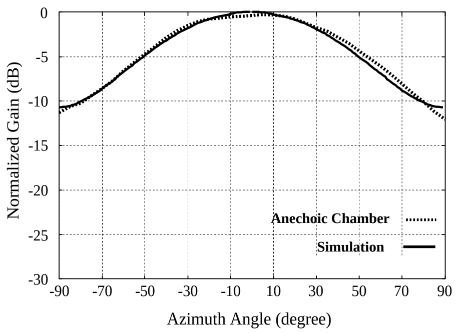

Figure 1: Simulated and measured E-plane pattern of rectangular microstrip.

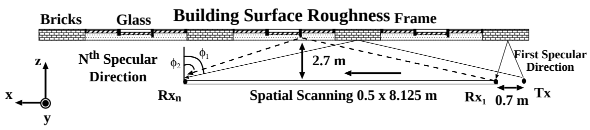

Figure 2: Top view of simulation arrangement.

are (0.85×1.5) m^2, (0.8×1.5) m^2, and (0.85×1.5) m^2. The three different window frames have outer dimensions of (0.04×1.5) m^2, (0.05×1.5) m^2 and (0.10×1.5) m^2, respectively. The first and the third window frames have the same offset depth of 0.16 m different from the second window frame that has 0.12 m offset depth. The windows are located 1.5 m from the ground. The wall surface, that has periodical roughness in both horizontal and vertical directions, is made of 0.1×0.05 m^2 bricks with 0.01 m gap among each other.

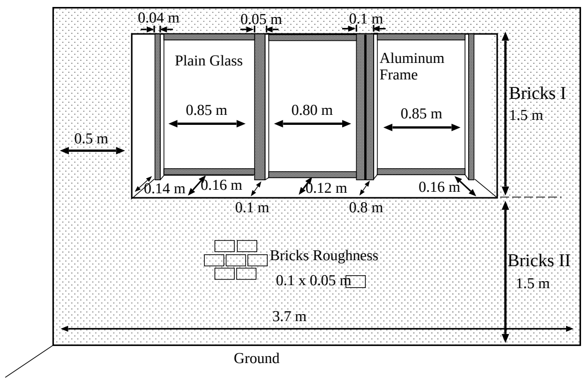

Figure 3: Building surface profile.

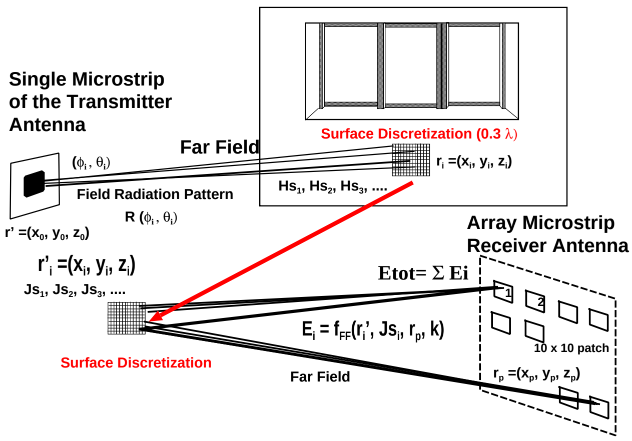

Figure 4: Strategy of wave scattering estimation.

4 Physical Optics Current on Impedance Surface

According to the field equivalence principle, equivalent currents on the illuminated part of the surface with impedance $Z[\Omega]$ are approximated by Eqs. (4) and (5) in the sense of Physical Optics (PO), where non-uniform terms are neglected. $\boldsymbol{E}^{inc}$ and $\boldsymbol{H}^{inc}$ are the incident electric and magnetic fields at the integration point, respectively. The parameter α is related to the reflection coefficients of the scatterer and is expressed as Eq.(6), where $\eta = \sqrt{\mu_0/\epsilon_0}[\Omega]$ and $Z = \sqrt{\mu/\epsilon}[\Omega]$ show the intrinsic wave impedance of free space and of the medium, respectively.

$$\boldsymbol{I}_{PO} = (1+\alpha)\boldsymbol{n} \times \boldsymbol{H}^{inc} \quad (1)$$

$$\boldsymbol{M}_{PO} = (1-\alpha)\boldsymbol{E}^{inc} \times \boldsymbol{n} \quad (2)$$

$$\boldsymbol{\alpha} = \frac{\eta - Z}{\eta + Z} \quad (3)$$

5 Wave Scattering Estimation

The prediction model to estimate the wave scattering on the building's surface consists of four parts. The first part is for calculating the radiation pattern or far field pattern from the transmitter antenna model. The second part is for obtaining the equivalent current on the building surface that has been discretized into smaller elements. The third part is for calculating the total field of the receiver antenna. Lastly, the fourth part is for getting the multipath signal using a superresolution technique.

The steps to acquire the current distribution on the building surface, which is defined as the second part of the method of approach, can be elaborated as follows: (i) Discretize the whole surface of building into N_s smaller elements. (ii) Determine the center of coordinate of each element into x_i, y_i, and z_i, $i \in N_s$. (iii) Determine the direction or vector in ϕ_i and θ_i with reference to the transmitter antenna for each element. (iv) Determine the illuminated region of the building surface using ray tracing. (v) Determine the electric field on the building surface that correponds to the gain of the transmitter antenna. (vi) Calculate the electric equivalent current of each element using PO approximation with impedance surface. (vii) Repeat this step for other wavelengths (λ_i).

The calculation steps defined as the third part is given as follows: (i) Determine the center of coordinate in x, y, and z of the receiver patch antenna. (ii) Determine the vector in ϕ_i and θ_i on the receiver patch antenna with reference to all centers of each element of the building surface. (iii) Determine the electric field on the patch from each element on the building surface that correponds to the gain of receiver antenna. (iv) Sum up all the fields from each element on the building surface for the patch of the receiver antenna. (v) Determine the total electric field on the patch of receiver antenna. After the total field of the patch receiver antenna has been obtained, continue the step for the other positions of the receiver array antenna.

In order to acquire the signal parameter from the array antenna, apply the 3D Unitary ESPRIT [4] by entering the total field of $N_p \times N_p$ receiver antenna. In this simulation $N_p = 10$ is applied. The analyses were performed at 60 observation points with an interval of 12.5 cm. Figure 4 show second part and third part of the method of approach for wave scattering estimation.

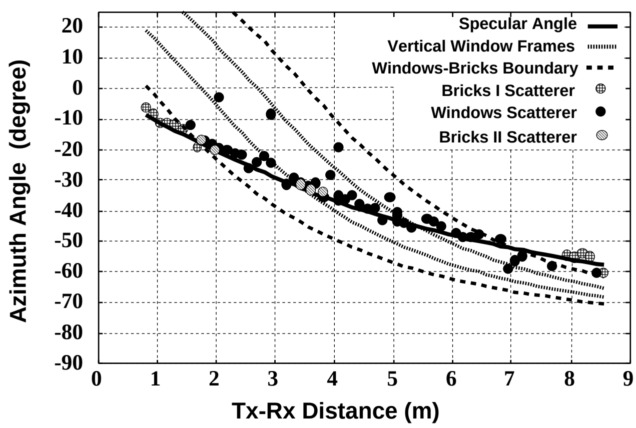

Figure 5: Azimuth angle of arrival wave.

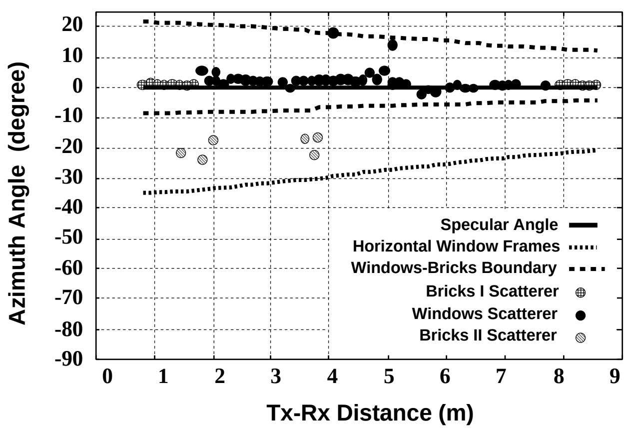

Figure 6: Elevation angle of arrival wave.

6 Simulation Result

The prediction model in this paper calculates the wave scattering from the building surface such as windows scatterer and bricks scatterer. The discretization of element on the building surface is 0.3 λ. Figure 5 shows the ESPRIT results for azimuthal angle of the arrival wave. Line of Sight (LOS) is defined -90° with respect to the receiver antenna. The figure also shows that most of the azimuthal angle values have a tendency to be distributed arround the angle of specular direction. This result is in good agreement with experimental investigations [1][2]. The diffracted wave from vertical and horizontal window frames are observed in a few scattering point in the distance range of at 2 to 5 meter between transmitter and receiver antennas. The diffracted wave satisfies to Keller's law of diffraction. Figure 6 shows the elevation angle of the arrival wave. It can be seen that the value of elevation angle is around 0° for those arrival waves coming from windows and bricks-I scatterers. It implies that most of the scattered waves from building surface arrives closely from specular directions. The arrival wave from Bricks II Scatterer can be observed in the figures.

Figures 7 and 8 show the path gain and delay time of arrival wave from windows and bricks scatterers, respectively. The path gain values of arrival wave are compared between experimental and simulation results. A good agreement is indicated between experiment and simulation results for the path gain of the reflected wave. Based on these results, the signal parameter of experimental result and of simulation result have little difference. The difference is attributed to the accuracy of the element discretized in the roughness of building surface and limitation of the PO approximation. Therefore, unlike experimental results, the second order scattering cannot be observed.

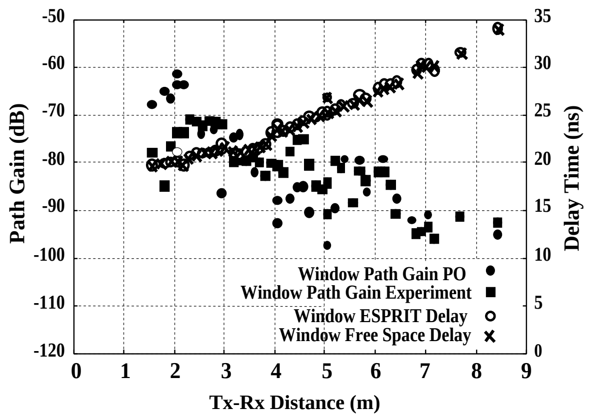

Figure 7: Path gain and delay profile of arrival wave from windows scatterer.

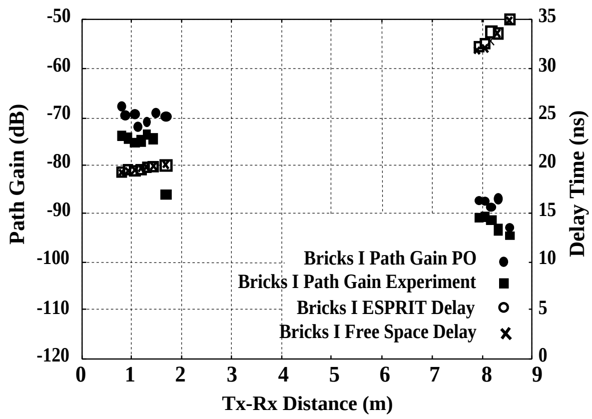

Figure 8: Path gain and delay profile of arrival wave from bricks scatterer.

7 Conclusion

This paper presents a propagation prediction model for non-specular wave scattering from building surfaces. The calculation method to calculate the total field of the receiver antenna consists of four parts: calculate the far field pattern of the transmitter antenna, determine the equivalent current on the building surface, calculate the total field on the receiver antenna, and finally obtain the multipath signal by applying ESPRIT. Numerical results show that the signal parameter profile is in good agreement with experimental results. However, a little difference between the numerical and experimental results. This difference is attributed to the accuracy of the element discretized in the roughness of the building surface and limitation of the PO approximation.

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