The Propagation Data Analysis For The Scatterer Field Intensity From 3D Building Surface Roughness

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Abstract

This paper reports the experimental results of the scatterer field intensity from 3D rough surface model of the building. The fluctuations of the field intensity due to the changes in the specular reflection point and material difference on the surface of building have been evaluated by Nakagami-m distribution and autocorrelation functions. The effects of the polarization and frequency are also reported.

Keyword : Wave Propagation, Building Surface Roughness, Scattering

1. Introduction

In the urban area, the buildings are the main scatterer which dominate the propagation characteristic in the mobile communication system. The electromagnetic wave propagation can be predicted by using ray tracing approach which incorporates reflection and diffraction. This approach is getting more popular in the propagation prediction and channel modeling in the mobile communication system. In the research of channel modelling for sub-urban [1], the surface is assumed to be flat, hence the magnitude of the reflected ray is also assumed to be constant. Therefore, when compared with the experimental results, the field strength in the ray tracing simulation cannot be sufficiently estimated.

However, the specular and non-specular scatterings for the surface roughness can also affect the channel characteristics. In order to demonstrate these effects, some researchers have assumed the scattering to follow Lambert’s law [4][5], which is applicable for the surface roughness characterized by random deviation of the surface height. Unfortunately, the above assumption does not seem to be applicable for the scattering from the building facade, whose windows and other architectural features have fairly periodic structure. For individual building, this periodic structure generates individual diffraction orders, rather than a continuum of diffused scattered power.

The authors had reported the effect of the field strength fluctuation from periodic structure of surface roughness in the two-dimensional simulation [2][3]. The numerical result showed that the field strength fluctuation increases with the increase of the incident angle and frequency. The PDF of the field strength of the reflection from the surface of the building can be well modeled by Nakagami-Rice distribution. The average loss and coherent length varies, depends on the incident angle and frequency. This paper presents the propagation data analysis for the scattered field intensity from three-dimensional building surface roughness based on the experimental result. The fluctuation of the field intensity and the autocorrelation function are evaluated as flat-fading parameters. Moreover, the time delay profile is taken to consider the frequency selective fading parameter.

2. Propagation Data Analysis Method

The scattered field strength from specular and non-specular direction, frequently applies the Nakagami-Rice distribution and Rayleigh distribution. It is possible to describe both the Rayleigh and Rician fadings with the help of a single model using the Nakagami-m distribution. The Nakagami-m distribution can represent a wider range of realistic fading condition. The parameter m in the distribution, controls the severity of the fading that the channel imposes on the transmitted signal amplitude. If the parameter m becomes smaller, then the degree of fading becomes more severe [7]. The PDF of Nakagami-m distribution is given as,

\[ p(R) = \frac{2}{\Gamma(m)} \left( \frac{m}{\Omega(m)} \right)^m R^{2m-1} \exp \left( -\frac{mR^2}{\Omega} \right), R \geq 0 \]  

(1)

where \( \Gamma(\cdot) \) is the gamma function and \( m \) is fading parameter or the shape factor (with a constraint that \( m \geq \frac{1}{2} \)) given by,

\[ m = \frac{E^2(R^2)}{E(R^2) - E(R^2)} \]  

(2)
The parameter $\Omega$ controls the spread of the distribution and is given by,

$$\Omega = E(R^2)$$  \hspace{1cm} (3)

In the special case for $m = 1$, the Nakagami reduces to Rayleigh distribution, and for $m > 1$, the fluctuations of the signal strength reduce compared with Rayleigh fading, and the Nakagami has a tendency toward Rician.

The fluctuation period of the signal strength is evaluated by the autocorrelation function. From the data, the following autocorrelation function was obtained,

$$\phi(k) = \frac{1}{N-k} \sum_{i=1}^{N-k} x^*(i)x(i+k),$$  \hspace{1cm} (4)

where $x(i)$ represents the $i$-th complex signal strength, and $k$ is the index of shift for reflection point. The autocorrelation coefficient $\phi(k)$ will be applied.

Discrete Fourier Transform (DFT) was utilized to obtain the time delay profile from the frequency selective fading parameter. The DFT is given as,

$$f(n) = \frac{1}{N} \sum_{k=0}^{N-1} F(k) \exp\left(\frac{j 2\pi n k}{N}\right)$$  \hspace{1cm} (5)

where $k$ is index of frequency domain data.

3. Experimental Method

The profile of the surface is shown in Fig. 1. This profile was taken from one of the buildings in Tokyo Institute of Technology. The surface of the building has non-uniformity due to the windows (glass), frames (aluminum), and wall (bricks). The surface has periodical irregularity along five periods. The height of the surface roughness was comparable with or larger than the wavelength. Parabolic antennas were used for transmitter and receiver with the diameters of 50 and 45 cm, respectively. The distance between transmitter and the specular reflection points, and the specular reflection point and receiver were both fixed as 2.7 m. The transmitter and receiver are simultaneously shifted up to two periods along the building surface to identify the effect from periodic surface and also to eliminate the effect of the change in distance from the intensity fluctuation due to the rough surface scattering. The transfer function was measured using network analyzer with the frequency range of 4.5 GHz to 6.3 GHz. In this experiment, H-H and H-V polarizations and 45° incident angles were used. The measurement data shall be normalized, in order to obtain the ratio of the field intensity from the measurement to the field intensity reflected from the surface of the Perfect Electric Conductor (PEC). The normalization with PEC can be represented by normalizing the data from the transmitter and receiver antennas positioned face-to-face [6].

4. Experimental Results

Figure 2 shows the scattered field intensity for the incident angle of 45° at frequency of 4.95 GHz, 5.4 GHz, and 6.3 GHz respectively for H-H polarization. The field intensity was normalized with field strength from face-by-face positioned transmitter and receiver antennas. Figure 3 shows the scattered field intensity for the incident angle of 45° at the frequencies 4.95 GHz, 5.4 GHz, and 6.3 GHz respectively for H-V polarization. Both figure 2 and 3 show that the field intensities at the glass reflection point and bricks reflection point are significantly different. Table 1 presents the average loss of co-polarization (H-H) and cross-polarization (H-V). Its average difference is 4.08 dB.

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<td>3</td>
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Figure 4 and 5 show the time delay profiles for two-period shift at 4.95 GHz with co-polarization. Figure 6 and 7 show time delay profiles for two-period shift at 4.95 GHz with cross-polarization. These figures demonstrate that the profile of time delay relative appeared to be similar with the profile of building surface roughness (see figure 1.). Therefore, it can be noticed that when the reflection point was at the glass surface, the reflection from inside the building was not significant for both H-H and H-V polarizations.

Figure 8 and 9 show statistical properties (CDF & ACF) of the field intensity for the incident angle of 45° at the frequency 4.95 GHz. The CDF is
Figure 2: The scattered field intensity with incident angle of 45° incidence for H-H polarization

Figure 3: The scattered field intensity with incident angle of 45° for H-V polarization

Figure 4: Time delay profile of field intensity for H-H Polarization at 4.95 GHz frequency

Figure 5: Contour of time delay spread for H-H polarization at 4.95 GHz frequency

Figure 6: Time delay profile of field intensity for H-V Polarization at 4.95 GHz frequency

Figure 7: Contour of time delay spread for H-V polarization at 4.95 GHz frequency
well approximated by the Nakagami-\(m\) distribution. The \(m\) parameter is 1.36. It shows that the specular component is more dominant compared with the diffused component. Table 2 presents \(m\) parameter for H-H and H-V polarization at the frequency of 4.95 GHz, 5.4 GHz and 5.85 GHz respectively. The significance of ACF is that antenna shifting which has less than the coherence length of the field intensities are received undistorted by the effect of surface roughness. The coherence length is 0.2 m for 0.72 correlation coefficient and antenna shifting is 0.1 m.

### Table 2: Average loss

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<td>3</td>
<td>5.85</td>
<td>1.38</td>
<td>1.31</td>
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Figure 8: Cumulative distribution function for H-H polarization at 4.95 GHz frequency

Figure 9: Auto correlation function of field intensity for H-H polarization at 4.95 GHz frequency

### 5. Conclusion

This paper presented the propagation data analysis for the scatterer field intensity from 3D building surface roughness. The field intensity at the glass reflection point and bricks reflection point are significantly different for H-H and H-V polarizations. It implies that when the reflection point was at the glass surface, the reflection from inside the building was not significant. The PDF of the field intensity of the reflection from the surface of the building can be sufficiently modeled by Nakagami-\(m\) distribution.

### 6. Future Work

Propagation data analysis of the field intensity for another incident angle and non-specular direction will be carried out. Three-dimensional numerical simulation model should be applied in this case to investigate more deeply the effect of periodic surface roughness.

### References


