行政院國家科學委員會補助專題研究計畫成果報告

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計畫編號：NSC 89－2213－E009－048－－
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計畫主持人：唐震寰
共同主持人：

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行政院國家科學委員會專題研究計畫成果報告
微細胞環境之三維無線電通道模型建構之研究

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主持人：唐震寰教授　　交大電信系

中文摘要

本文提出合併模型，研究微細胞(都會區)無線電波多重路徑衰落(multipath fading)的特性。它是由二維適應環境式模型(Site-Specific Model)和散射模型組合而成，適應環境式模型可包含傳播環境中邊界的反射、散射及穿透效應，而散射模型則可用來描述傳播環境中隨機擺放的散射體或粗糙表面邊界，所造成的散射場。該模式能減少適應環境式模型中射線追跡的樹狀階層數，進而大量節省計算時間，同時可精確地預估平均場強值，並藉由相對散射參數 r 有效地量化傳播環境中之散射場分量(相對於平均值)的貢獻。不同地點的大量實驗數據(900-MHz 於微細胞)顯示 Nakagami 分佈可有效地描述振幅的衰落分佈（Amplitude fading distribution）。經實地量測，我們發現在在微細胞模型，因發射及接收天線均處於輕微散射的環境中,當 r 設定 0.1~0.2 ，既可有效 model 不同環境之無線電波多重路徑衰落的統計特性。

Abstract

In this report, we present a hybrid model to investigate the characteristic of multipath fading in microcellular (urban) environment. It is composed of a 2-dimensional site-specific model and a scattering model. The site-specific model comprises the reflection, scattering and transmission effects of the boundaries in the transmission environment. Scattering model can be used to describe the scattering field as a result of random distribution of scattering object and the rough surface boundary. It is found that this treatment can decrease the number of ray-tree levels of the site-specific model and saves a lot of computational time. In addition to accurately predicting mean field strength, the hybrid model can effectively quantify the contribution of scattering field (relative to mean value) with the relative scattering factor r.

A large amount of experiment data acquired at different sites in microcellular urban environment shows that a Nakagami distribution describes the fading distribution well. It is found that our model can characterize the amplitude fading property well to compare with the measurement data by choosing r=0.1~0.2. This result demonstrates a fact that both transmitting and receiving antennas are at light cluttering environment.

Keywords: **Fading channels, site-specific models, Nakagami distribution, Microcell**

1. Introduction

To improve the system capacity, the cell size of microcellular systems is less than 1 km in diameter. Their base stations will be mounted on, for example, lampposts or building rooftops, and will be connected to the public-telephone network. As a result of the increased frequency re-use provided by the microcellular structure, it should be possible to accommodate more users in roughly the same amount of spectrum used in cellular systems.

For UHF radio propagation in an urban street environments, typically there are many reflectors existed such as the building walls along the street, and randomly positioned scatters such as vehicles, pedestrians, trees, lamp posts and street signs. Therefore, in a statistic microcellular channel, the received signal is composed of energy which is reflected, transmitted, or scattered by all objects that existing in the propagation environment.

In this work, a patched-wall model is used to model the characteristics of urban microcellular environment. Patches of different dielectric constants and sizes are used to describe the street walls according to each physical structure and dimension.

To characterize the fading statistics of the channels, an analytical hybrid scattering model, combining the 3-D site-specific model and a statistical model, is developed to analyze the statistical characteristics of received signal (that including the small-scale fading and received power) for microcellular radio channel in urban environment. The experimental data measured in urban streets validates the performance of the hybrid model.

2. Hybrid model

In the hybrid model, the electric field after received by the antenna is determined by a superposition of deterministic and random rays. It can be expressed as

$$E_r = E_{dr} + E_{sr} \qquad (1)$$

E_{dr} is equal to the summation of deterministic ray fields due to the average or effective environment which are computed by the site-specific model [1,2] E_{sr} is a random field with zero mean, which describes the received field due to rough surface boundaries and/or randomly positioned scatters.

A novel 3-D site-specific diffused reflection model is developed to evaluate the average path loss of the microcellular channels in urban environment. In this model, an analytical scattering model, combined with a patched-wall model evaluates the average path loss more accurately than the conventional analytical ray-tracing model in the cases studied. The patched-wall model has been used to model an indoor radio channel using patches of different dielectric constants and sizes to model indoor walls and boundaries [2].

The proposed model includes three major propagation modes: (1) a direct-path wave, $\vec{E}_D$; (2) a ground-reflected wave, $\vec{E}_G$; and (3) the diffused-reflected fields from the walls aligned along the streets, $\vec{E}_S$. Summation of these waves determines the receiving field at an observation position and yields

$$\vec{E}_R = \vec{E}_D + \vec{E}_G + \vec{E}_S \tag{2}$$

The ground-reflected wave, is given by

$$\vec{E}_G = \vec{E}_o G_t G_r L_f(d) R_g(\theta_g) \tag{3}$$

where $\vec{E}_o$ is the field 1-meter away from the transmitting antenna. G_t and G_r are the field amplitude radiation patterns of the transmitting and the receiving antennas, respectively. $L_f(d) = \frac{e^{-j\beta d}}{4\pi d}$ is the free-space propagation factor with an unfolded path length d. $R_g(\theta_g)$ is the Fresnel reflection coefficient of ground with an incident angle θ_g. It is noted that the expression of $\vec{E}_D$ can be obtained from Eq.(3) by setting $R_g = 1$.

The vector field, $\vec{E}_S$, is equal to the summation of all the diffused-reflected fields from every patch of the both walls aligned along the measured street and is given by

$$\vec{E}_S = \sum_{j=1}^{m} \vec{E}_j^s \tag{4}$$

The jth diffused-reflected field $\vec{E}_j^s$ at the observation position is due to the incident field $\vec{E}_j^i$ diffused by the jth patch and is given by

$$\begin{bmatrix} E_{\alpha 2}^S \\ E_{\beta 2}^S \end{bmatrix}_j = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_j \begin{bmatrix} E_{\alpha 1}^i \\ E_{\beta 1}^i \end{bmatrix}_j \tag{5}$$

where [S] is the polarization scattering matrix (PSM) [5]

The incident field arriving at the jth patch, $\vec{E}_j^i$, is given by

$$\vec{E}_j^i = \vec{E}_o G_{tj} L_f(d_{Tj}) \tag{6}$$

where $L_f(d_{Tj}) = \frac{e^{-j\beta d_{Tj}}}{4\pi d_{Tj}}$ and G_{tj} is the field-amplitude radiation pattern of the antenna. d_{Tj} represents the distance between the transmitting antenna and the center of the *jth* patch.

The component of the PSM due to the *jth* patch, S_{lk}, is related to the corresponding radar cross section (RCS), σ_{lk}, by

$$S_{lk} = \frac{\sqrt{\sigma_{lk}}}{\sqrt{4\pi} d_{sj}} \tag{7}$$

where d_{Sj} is the distance between the jth patch center and the observation position, and *l, k=1 or 2.* For a rectangular patch $(L_x \times L_y)$, σ_{lk} is given by [4,6]

$$\sigma_{lk} = \frac{k^2}{\pi}(L_x L_y)^2 \left(\frac{\sin k \xi_x L_x / 2}{k \xi_x L_x / 2}\right)^2 \left(\frac{\sin k \xi_y L_y / 2}{k \xi_y L_y / 2}\right)^2 |\gamma_{lk}|^2 \tag{8}$$

2-1 Scattering Model

The receiving scattered field is formulated as

$$E_{sr} = E_o \sum_{n=1}^{N} \exp(j\phi_n) \tag{9}$$

where ϕ_n is a random phase that is uniformly distributed throughout 0 to 2π; N is the total number of received rays; and E_o is an arbitrary constant. Notably, with statistical characteristics of the parameters in Eq. (9), $|E_{sr}|$ should follow a Rayleigh distribution. In addition, the spatial correlation function of the scattered field can be derived and given by

$$R_{E_{sr}}(d) = \langle E_{sr}(r) E_{sr}^*(r+d) \rangle = N E_o^2 J_o(kd) \tag{10}$$

where $\langle \cdot \rangle$ and J_o are the ensemble average and the zero-order Bessel function of the first kind, respectively; and k and d are the free-space wavenumber and spatial distance, respectively.

3. Measurement Procedure and Modeling of Environment

Narrow-band (CW) signal strength measurements were made at 900-MHz at three sites. Site A, is located in Chu-tung; sites B and C, are in Hsin-Chu. Figure 1 illustrates typical street buildings along the street. Since the features of the buildings along the both streets are similar, they are modeled as an uniform array of construction or building unit, which is shown in Fig. 2. During the measurement, a half-wavelength dipole antenna transmitted a 14 dBm CW signal; the antenna was sited 6 m above the ground, mounted on a measuring pole that was tied to a tree near the sidewalk. The receiving antenna, a half-wavelength dipole antenna, was mounted on the rooftop of a test van, which was moving along a roadway, and its height was 2.3 m above ground. A PC-controlled receiver (CHASE GPR4427A), continuously sampled the received power every half wavelength along each measured route. The data processo sampled the digitized received field strength and was triggered by a wheel sensor to send out required sampled data to a data acquisition system controller (a notebook PC). The wheel sensor transmitted a series of periodic pulses and operated as a distance pulse generator.

For each measured point (sector), 66 samples taken within a distance of 30 wavelengths determine the probability density distribution of the received power in the associated distance. From the probability distribution of the received power, the measured average can also be evaluated.

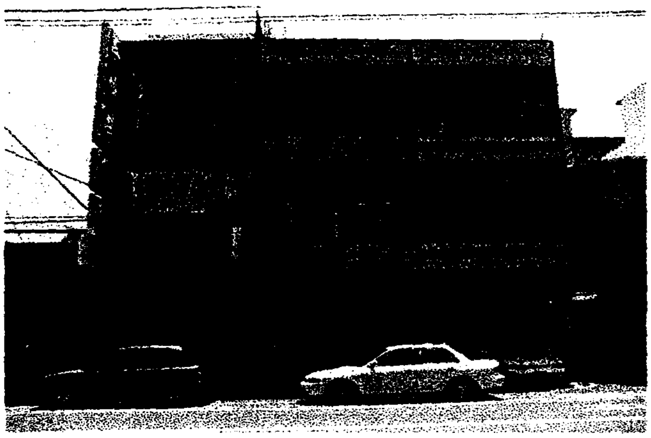

Fig.1 Picture of typical street buildings at site A

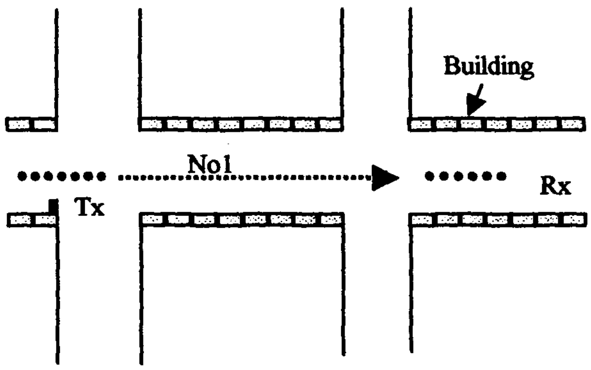

Fig.2 Layout of site A(Chu-Tung):Top view.

4. Comparison and Discussion

A. Computation of the scattered field

Since the $(i+1)^{th}$ sampled complex scattered field is related to the i^{th} sampled field, their relation can be described using AR-1 (First-order Autoregressive Model) method [3]

$$E_{sr}(i+1)=E_{sr}(i)R_{\rho}+\sqrt{1-R_{\rho}^2}\,[N_1(0,\sigma)+jN_2(0,\sigma)]. \quad (11)$$

where R_ρ is the normalized R_{Esr}. $N_1(0,\sigma)$ and $N_2(0,\sigma)$ both are independent Gaussion random variables with zero mean and same standard deviation σ. Since $|E_{sr}|$ follows a Rayleigh distribution, $\sigma=\sqrt{\frac{2}{\pi}}<|E_{sr}|>$. Herein, value of σ or $<|E_{sr}|>$ is determined from the experimental data.

To determine σ more easily, a factor $r = {<|E_{sr}|>}/{|E_{d}|_{av}}$ is defined with $|E_{d}|_{av}$ being the spatially averaged deterministic envelope.

B. Comparison

Figure 3 illustrates the receiving power at site A. Figure 4 demonstrates measured and computed probability density distributions (PDDs) of signal amplitude of position No.1 at site A. We can find that the hybrid model with a properly chosen value of r yields better prediction accuracy than that of the traditional site-specific model. It is ound that r=0.12 yields the best prediction accuracy at that point. Figure 5 displays measured and computed probability density distributions of signal amplitude for a specific receiving position at sites B. It is also found that the optimum values of r for positions No.1 (at site B) is equal to 0.17. It seems that it is in a light clutter environment. Table I summarizes the relative scattering factor r of 18 measured positions at microcellular environment.

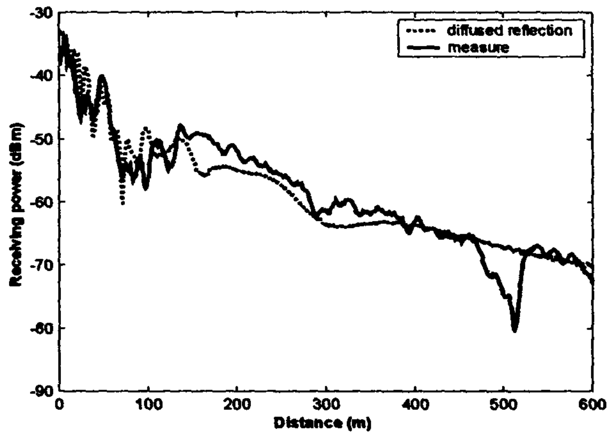

Fig.3 Receiving power along the measured route at site A.

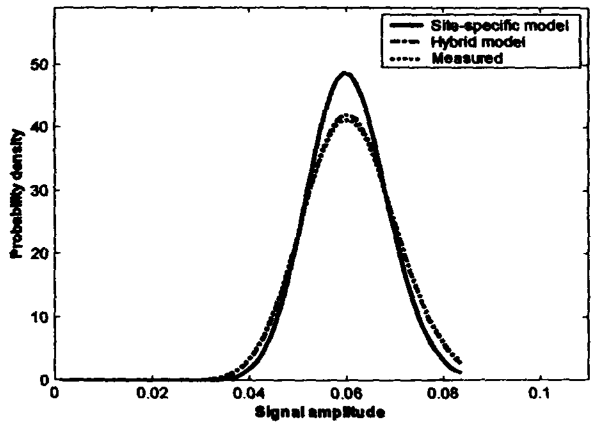

Fig.4 Probability density distribution of measured and calculated signal of amplitude of position No.1 at site B in microcellular environment (r=0.12).

5. Conclusion

For radio propagation in microcellular environment, a novel hybrid model is developed to evaluate the small-scale fading, for microcellular radio channel in urban environment. The hybrid model is composed of a site-specific model with a statistically scattering model. The former model employs physical optics to treat the diffused reflection field and evaluates deterministic received power. The statistical model describes the fields due to randomly positioned scatters around the receiver may affect localized fading distribution. Here, the effect is not significant due to direct path existed between the scatters and the receiver. Therefore, it is a light cluttering environment and r is in the range of 0.1~0.2. This result may need to be modified to consider local scattering effect, when the receiving antenna (mobile unit) is inside a vehicle.

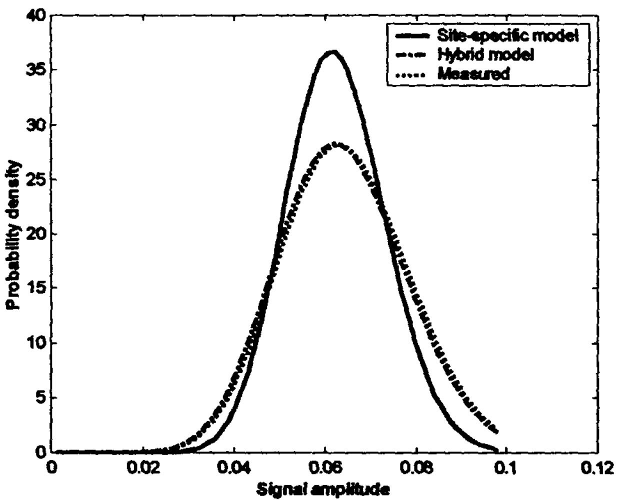

Fig.5 Receiving power along the measured route at site B.

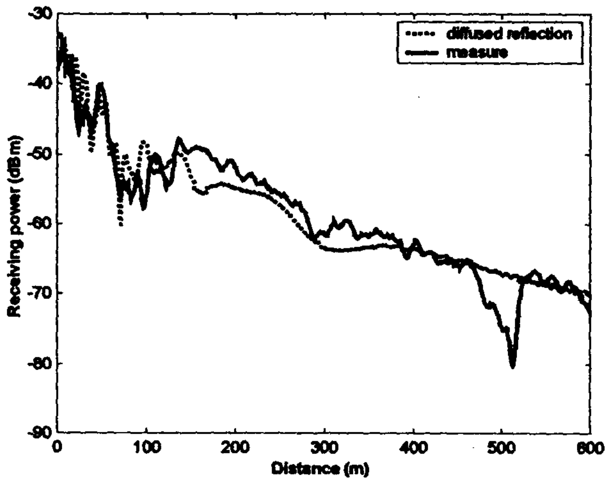

Fig.6 Probability density distribution of measured and calculated signal of amplitude of No.1 at site B (r=0.17).

6. References

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Table I Relative scattering factor r for 18 positions located at microcellular environment (site A, site B, siteC)

Site\ r \Distance(m)	100	150	200	250	300	350	400
site A	0.12	0.12	0.11	0.16	0.2	0.14	0.12
site B	0.17	0.12	0.11	0.2	0.13	0.15	0.18
site C	0.22	0.22	0.19	0.2	0.2	0.16	0.13