Proposal of Method for Estimating Received Signal Characteristics in Mobile Communication Environments

Yoshikazu Asano

Abstract—**A method for estimating the received signal characteristics (MERS) is developed. The MERS aims at estimating the received power and the fading spectrum at the mobile in mobile communication environments. In the MERS, these characteristics are estimated on the basis of both an angular probability density distribution (APD) of wave arrival and a radiation pattern. The APD can also be estimated under arbitrary environmental conditions in the MERS. For the estimation of the APD of wave arrival, a novel propagation model is proposed in this paper. The model consists of an environment model that represents the statistical features of the configuration of buildings along streets and a path model that represents geometrical propagation paths from a transmitting point to a receiving point on the streets. The estimated results of the received signal characteristics are compared with the measured ones. It is proved that the received power and the fading spectrum can be closely estimated.**

Index Terms—**Fading channels, land-mobile communications.**

I. Introduction

A MOBILE communication antenna that conforms to a car body surface and mounted inside the car has lately attracted considerable attention in preventing breakage and burglary. Such a car antenna has to be integrally designed with the car body. Therefore, the estimation of the signal characteristics received by the antenna in mobile communication environments is required. In particular, the averaged characteristics within a region (estimation region) from 500 m to 1 km on a street are significant because the evaluation of the car antenna is based on the averaged communication quality.

The received signal characteristics can be theoretically calculated from an angular probability density (APD) distribution of wave arrival and a radiation pattern [1]. However, the APD of wave arrival under arbitrary environmental conditions, such as building's configuration, street width and street angle is required for the application of the theory [2], [3].

The following methods have already been proposed to obtain the APD of wave arrival for mobile communication environments.

1) The method for calculating the APD based on the power received by the antenna with a sharp beam [4].
2) The method for assuming the APD to be uniform in the azimuthal plane and Gaussian in the vertical plane [5].

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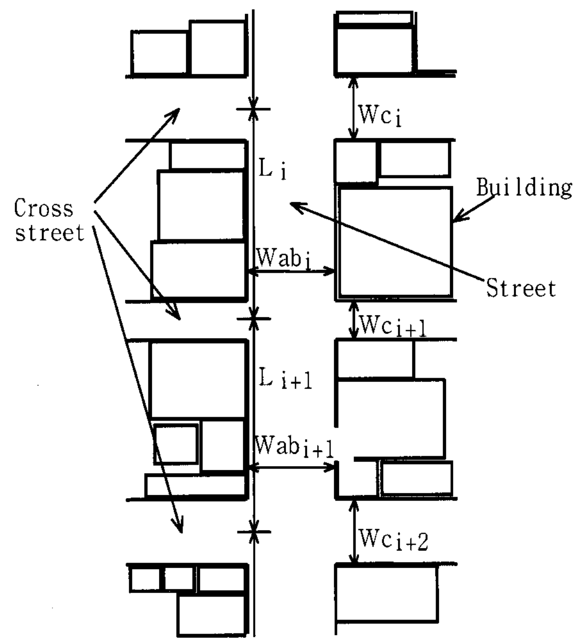

Fig. 1. Typical environment in urban area.

The former has been applied to the prediction of level crossings. The predicted results have shown good agreement with the measured ones [4]. However, it is not easy to obtain the APD of wave arrival under arbitrary environmental conditions. Similarly, in the latter method, the standard deviation and the maximum direction of the Gaussian distribution cannot be easily determined under arbitrary environmental conditions in the vertical APD. Also, in the azimuthal APD, it is impossible to take the environmental conditions into account.

This paper proposes a novel propagation model that is capable of estimating the APD of wave arrival under arbitrary environmental conditions. The proposed model is suitable for estimating the APD of wave arrival averaged within an estimation region that is essential for the estimation of the averaged characteristics of the signal received by the car antenna. In addition, a method for estimating the received signal characteristics (MERS) is developed on the basis of the proposed propagation model. Furthermore, the applicability of the MERS to the estimation of the received signal characteristics is discussed through a comparison between the estimated characteristics and the measured ones.

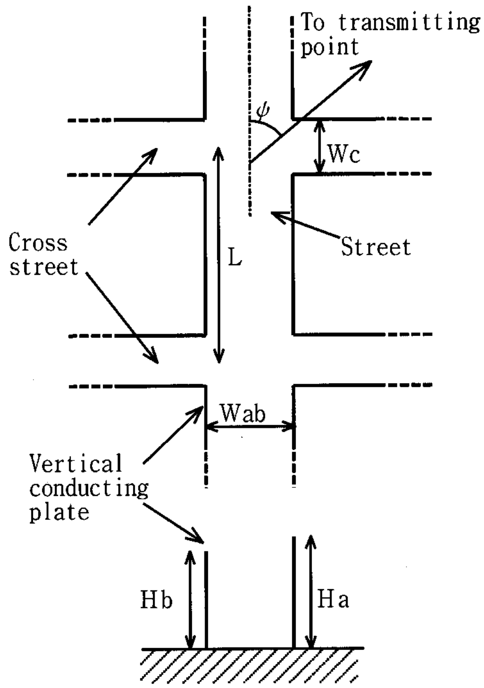

Fig. 2. Environment model to represent statistical features of environmental conditions.

II. Proposal of Propagation Model

The propagation model suitable for estimating the APD of wave arrival averaged within the estimation region is proposed in this chapter. The APD's of wave arrival measured around crossings are much different from those measured at other points [6], because the APD's of wave arrival around the crossings are influenced by the wave arrivals along the cross streets. The influence of such waves around the crossings should be taken into account for the proposed propagation model. Therefore, the author basically adopts a geometrical model and not a statistical one like the Suzuki model [7] in which the wave arrivals are dealt with independent of the street direction.

The geometrical model generally needs precise environmental data such as the dimensions of the buildings, etc., in the estimation region. For the estimation of the averaged APD of wave arrival, however, such precise data on the environmental conditions is not necessarily indispensable. The statistical data on the environmental conditions in the estimation region are presumably rather important. Therefore, both an environment model to represent the statistical features of the environmental conditions and a path model to represent the geometrical propagation paths from a transmitting point to a receiving point on the streets are combined in the proposed propagation model. The wave arrival is geometrically determined in the simple virtual environment that possesses the statistical features in the estimation region. Thus, the proposed propagation model seems to belong to a new category, the combination of a statistical model with a geometrical model.

A. Environment Model

The environment model represents the statistical features of a typical environment in an urban area, as shown in Fig. 1. The rows of buildings along the street are cut into pieces by the cross streets with interval L^i. The street width is Wab^i and the cross street width is Wc^i. The author proposes the environment model as shown in Fig. 2 for the above environment. This model possesses a periodic structure. The period is a region whose ends are cross streets. In the model, the buildings along the street are substituted by the vertical conducting plates with constant heights Ha and Hb on each side of the street. As these values, the 70% values of the cumulative distributions of the building height on each side of the street within the estimation region are empirically used. The street angle ψ is defined as an angle between the direction of the street and the direction to a transmitting point. In the model, the cross streets are perpendicular to the street. The street width Wab, the cross street width Wc and the interval L between cross streets are constant; these values are obtained by averaging the corresponding values within the estimation region.

Thus, arbitrary environmental conditions can be easily accounted for by these environment parameters; that is, Ha, Hb, Wab, Wc, L, and ψ, in the environment model. Within the parameters, the cross street width, the interval between cross streets, and the street angle are included. Therefore, the model is capable of dealing with the wave arrivals from cross streets and taking the street angle into consideration. In addition, the periodic structure of the model enables us to simplify the calculation of the averaged APD of wave arrival. This is because we can obtain the APD of wave arrival averaged over the entire of the estimation region by only averaging the APD at the receiving points in one period.

B. Path Model

The path model represents radio wave propagation paths from a transmitting point to a receiving point within one period of the environment model. The author obtains the model by modifying the ray theoretical model proposed by Ikegami [8]. Each propagation path in the path model consists of the propagation path1 and the propagation path2 as shown in Fig. 3. The propagation path1 represents the path from the transmitting point to a diffraction point; path2 is from the diffraction point to the receiving point. The diffraction point in each propagation path exists on the edge of the conducting plate corresponding to the roof edge of a building. The point shifts for the receiving point.

1) Propagation Path1: The propagation path1 is assumed to be in line of sight. In addition, a reflection path, which contains the reflection on a tall building wall commonly visible from both the transmitting point and the diffraction point, is also taken into account by the path1. For such a path, a reflection point on the wall is regarded as a secondary transmitting point.

2) Propagation Path2: In the ray theoretical model, reflected waves and diffracted waves are the dominant ones. The author adds scattered waves to these waves for the definition of ray paths. The scattering is assumed to occur on the conducting plate because of the surface roughness on the front walls of

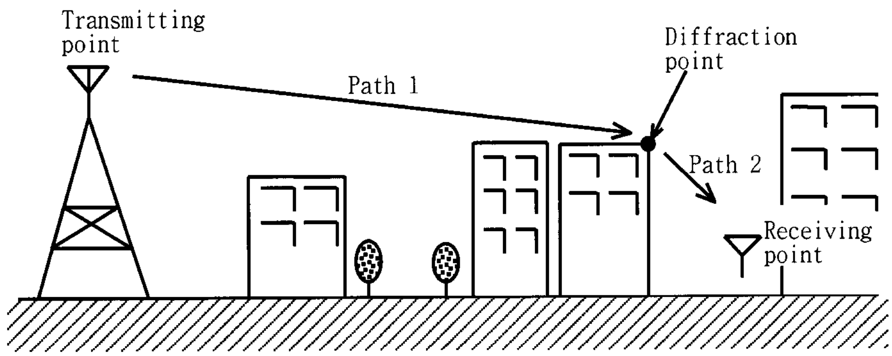

Fig. 3. Path model to represent geometrical propagation paths from transmitting point to receiving point.

the buildings. The scattered power per unit solid angle, which arrives at a receiving point from a specific direction, is assumed to propagate on the ray path from that direction. Based on this assumption, the ray paths for the scattered waves can be defined in the same way as those for the reflected waves and diffracted ones. Thus, the propagation path2 is expressed by the combination of the reflection and the scattering after the diffraction. Here, the reflection is assumed to be twice or less due to the degradation of the field strength by the reflection. Moreover, reflection, diffraction or scattering is assumed not to occur after scattering. Therefore, propagation paths accounted for in the path model are summarized as follows:

$$\text{diffraction} \rightarrow n\text{-time reflection} \rightarrow m\text{-time scattering}$$
$$(n = 0, 1 \text{ or } 2; m = 0 \text{ or } 1; n + m \leqq 2).$$

Fig. 4 shows an example of the paths with scattering. The horizontal directions of these paths at a receiving point depend on the street angle ψ. In the definition of the paths, the disappearance of the conducting plate along the street at the crossing has to be taken into consideration. On the other hand, the paths with the scattering exist in almost all-azimuthal directions because the scattering is assumed to occur at any place on the conducting plates irradiated with diffracted waves and diffracted–reflected waves.

Thus, the propagation paths from a transmitting point to a receiving point are easily defined by the proposed propagation model. Furthermore, the length of each propagation path, that is, the arrival delay time, can also be calculated on the basis of the defined propagation path. Therefore, the model can be applied to the estimation of not only the spatial APD of wave arrival, but also the temporal one. Consequently, the proposed propagation model presumably possesses a good applicability.

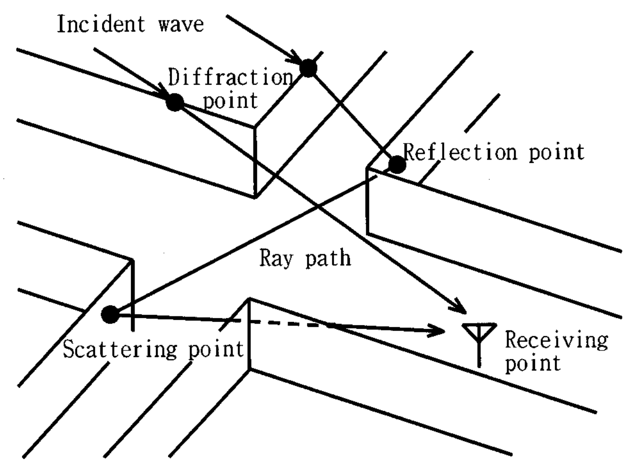

Fig. 4. Some propagation paths contained in propagation path2.

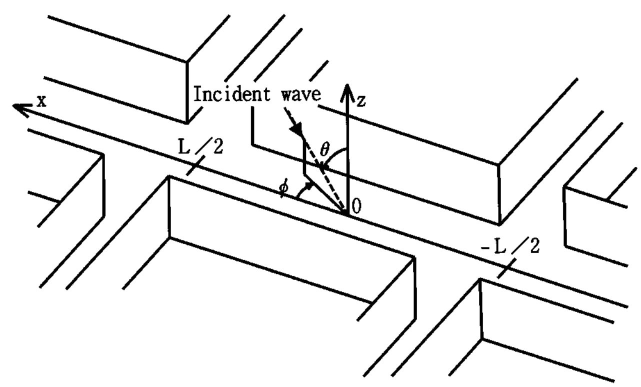

Fig. 5. Environment model and its coordinate system.

III. Method for Estimating Received Signal Characteristics (MERS)

The MERS consists of the following two methods.

1) The method for estimating the averaged APD of wave arrival on the basis of the proposed propagation model.
2) The method for estimating the received signal characteristics from the estimated APD and a radiation pattern.

A. Estimation of APD of Wave Arrival

The averaged APD of wave arrival is estimated by the propagation model according to the following procedures.

The values of the environmental parameters in the environment model are first determined on the basis of the environmental conditions within an estimation region. From

TABLE I
SPECIFICATIONS OF SYSTEM FOR MEASURING RECEIVED POWER AND FADING SPECTRUM

Channel sounder	Unmodulated CW carrier
Carrier frequency	1.2GHz band
Polarization	Vertical
Tx. power	10W
Tx. antenna	17-element Yagi antenna
Tx. antenna height	110m above ground
Rx. antennas	A half-wave length dipole antenna & two-direction antenna
Rx. antenna height	1.5m above ground
Distance between Tx. and Rx.	13-14km

these values, the environmental model as shown in Fig. 5 is fixed. A coordinate system in the model is also shown in this figure. Second, the propagation paths, which arrive at receiving points x on the x-axis, are defined. The arrival direction (θ, ϕ) and the delay time τ of each radio wave, which propagates along the corresponding defined propagation path, are then known. Finally, the power of each wave can be obtained by subtracting the free-space propagation loss and the other power losses from the effective transmitted power containing the transmitting antenna gain. Here, diffraction loss Ld, reflection loss Lr and scattering loss Ls are accounted as the power losses; Lr and Ls are subtracted by n and m times, respectively, as defined by the propagation path2. Ld is calculated by assuming knife-edge diffraction [9]. Lr is assumed to be a constant 8 dB; the value of Lr is calculated as a reflection loss for the normal direction on a concrete wall whose relative dielectric constant is $5.5 - j0.32$. Ls is calculated assuming a cosine scattering pattern (see Appendix).

The arrival direction, the delay time and the power of each radio wave, which arrives at receiving points x on the x-axis, are determined according to the above procedures. It then follows that the spatial and temporal arrival power distribution P of x, θ, ϕ and τ at the receiving point x can be obtained. Here, P expresses the power density per unit solid angle and unit delay time. Furthermore, the APD $\Gamma(\theta, \phi, \tau)$ of wave arrival is given by averaging the distribution $\Gamma(x, \theta, \phi, \tau)$ within the period L and normalizing the distribution.

Thus, the averaged APD of wave arrival of interest can be easily obtained by averaging the distributions at the receiving points within only one period

$$\Gamma(\theta, \phi, \tau) = \frac{\frac{1}{L}\int_{-L/2}^{L/2} P(x, \theta, \phi, \tau)\, dx}{\int_0^\infty \int_0^{2\pi} \int_0^\pi \frac{1}{L} \int_{-L/2}^{L/2} P(x, \theta, \phi, \tau)\, dx \, \sin\theta \, d\theta \, d\phi \, d\tau}. \tag{1}$$

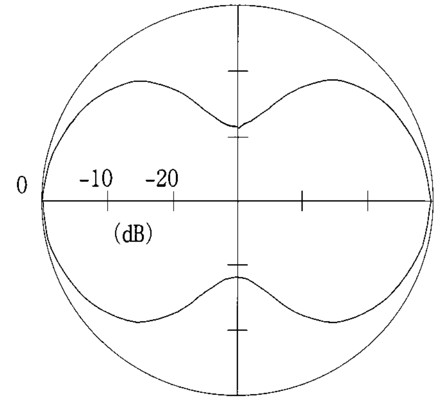

Fig. 6. Azimuthal radiation pattern of two-direction antenna used in experimental measurements.

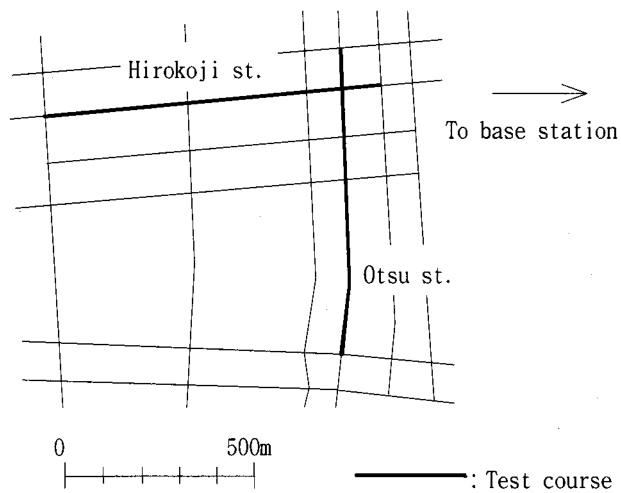

Fig. 7. Map of test courses at Sakae in Nagoya city for measurements of received power and fading spectrum.

B. Estimation of Received Signal Characteristics

The received signal characteristics are estimated from the averaged APD of wave arrival and the radiation pattern of a car antenna.

1) Received Power: The received power Pre is calculated from the radiation pattern $G(\theta, \phi)$ of the receiving antenna and the APD $\Gamma(\theta, \phi, \tau)$ of wave arrival using (2) [1]

$$Pre = Piso \int_0^{2\pi} \int_0^\pi G(\theta, \phi) \times \int_0^\infty \Gamma(\theta, \phi, \tau)\, d\tau \, \sin\theta \, d\theta \, d\phi \tag{2}$$

where $Piso$ is the power received by an omnidirectional antenna and is calculated using

$$Piso = \int_0^\infty \int_0^{2\pi} \int_0^\pi \frac{1}{L} \times \int_{-L/2}^{L/2} P(x, \theta, \phi, \tau)\, dx \, \sin\theta \, d\theta \, d\tau. \tag{3}$$

2) Fading Spectrum: The fading spectrum denotes the base-band power spectrum of the received signal after

TABLE II
VALUES OF ENVIRONMENTAL PARAMETERS USED IN ESTIMATION OF RECEIVED POWER AND FADING SPECTRUM

Test course	Ha(m)	Hb(m)	L(m)	Wab(m)	Wc(m)	ϕ (deg)
Hirokoji st.	44	33	107	30	20	5
Otsu st.	30	31	99	35	10	85

TABLE III
COMPARISON BETWEEN ESTIMATED RECEIVED POWER AND MEASURED POWER

Test course	Antenna condition	Estimated (dBm)	Measured (dBm)	Estimation error (dB)
Hirokoji st.	Omnidirectional case	-92.4	-94.7	2.3
	Parallel case	-89.6	-91.2	1.6
	Perpendicular case	-104.5	-100.3	-4.2
Otsu st.	Omnidirectional case	-97.4	-99.3	1.9
	Parallel case	-96.8	-97.2	0.4
	Perpendicular case	-95.1	-98.7	3.6

square-law detection. The spectrum has frequency components that are less than twice the maximum Doppler shift fm. The fading spectrum is calculated by the self convolution of the input spectrum $I(f)$ [10]. The input spectrum is given by

$$I(f) = \int_{(\sigma)} G(\theta,\phi) \int_0^{\infty} \Gamma(\theta,\phi,\tau)\, d\tau \sin\theta\, d\theta\, d\phi \quad (4)$$

where the integral range σ is the region in which $f = fm \cdot \sin\theta \cdot \cos\phi$ is satisfied.

Consequently, it follows that the received signal characteristics can be estimated using the MERS under arbitrary environmental conditions and for arbitrary radiation pattern of the car antenna. Therefore, the MERS can be used as a tool for designing mobile communication antennas so that the optimal received signal characteristics can be obtained.

IV. EXPERIMENTAL MEASUREMENTS

The measured data of the received power and the fading spectrum were obtained in Nagoya city, Japan, in order to discuss the applicability of the MERS to the estimation of the received signal characteristics. The measurement system, which has the specifications shown in Table I, was used. An unmodulated continuous wave (CW) carrier in the 1.2-GHz band translated from the base station was received at the mobile station. As a receiving antenna, a half wavelength dipole antenna and a two-direction antenna were used. The two-direction antenna possesses the radiation pattern shown in Fig. 6; the gain of the antenna in the azimuthal plane is 2.5 dB larger than that of the half wavelength dipole antenna. The measurements with the two-direction antenna were carried out both in the case where the beams of the antenna were directed parallel to a street and in the case where that of the antenna was directed perpendicular to the direction of the street. The author represents the former case and the latter case as the parallel case and the perpendicular case, respectively. Moreover, the case when a dipole antenna was used is represented as the omnidirectional case.

Hirokoji street and Otsu street in Fig. 7 were chosen as the test courses at Sakae in Nagoya city. There are many high-rise buildings at Sakae. The strength of the received carrier wave was measured every 1.5 cm on the two test courses. On the basis of the measured results, the received power and the fading spectrum averaged within each test course are given.

V. COMPARISON BETWEEN ESTIMATED RECEIVED SIGNAL CHARACTERISTICS AND MEASURED ONES

This chapter discusses the applicability of the MERS to the estimation of the received signal characteristics through the comparison between the estimated characteristics and measured ones. For the estimation of the received signal characteristics, the values of the environmental parameters in Table II are used.

A. Received Power

Table III shows a comparison between the estimated received power and the measured one. Fairly good estimation results are obtained for all cases, though the estimation errors in the perpendicular case are slightly larger than those in the other cases. In addition, the measured result on Hirokoji street varies in the range of 10 dB between the three cases. On Otsu Street, a small variation in the measured result is seen. These variation tendencies in the measured results also appear in the estimated ones. It is found from the above comparison that the MERS can estimate the received power by considering the environmental conditions and the radiation pattern.

In the MERS, scattered waves are taken into account. The waves are normally weaker than the diffracted waves and the diffracted–reflected waves which can be regarded as the dominant ones in urban areas [8]. Therefore, the author discusses the influence of scattered waves on the received power

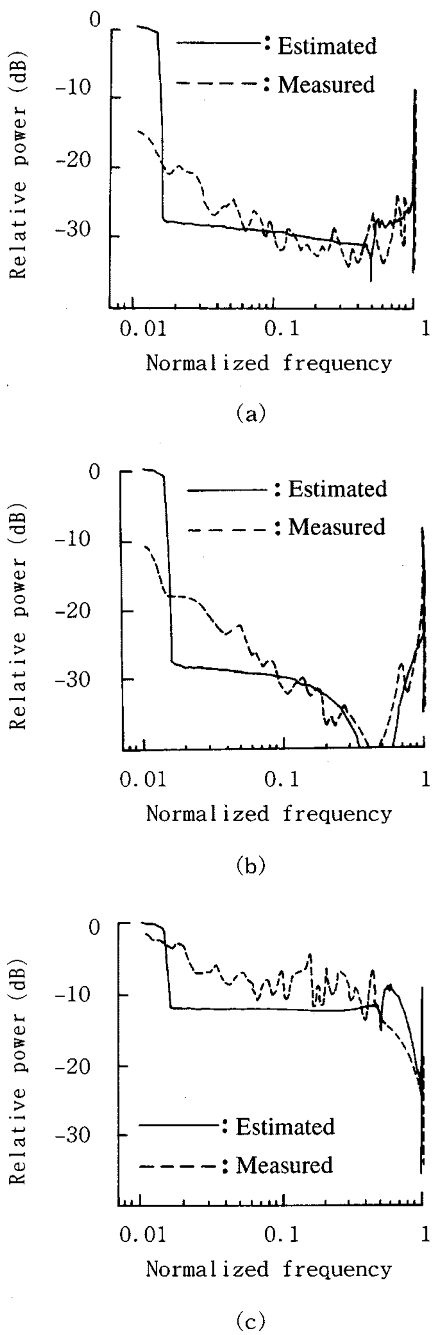

Fig. 8. Comparisons between estimated fading spectra and measured ones in (a) omnidirectional case; (b) parallel case; and (c) perpendicular case on Hirokoji Street.

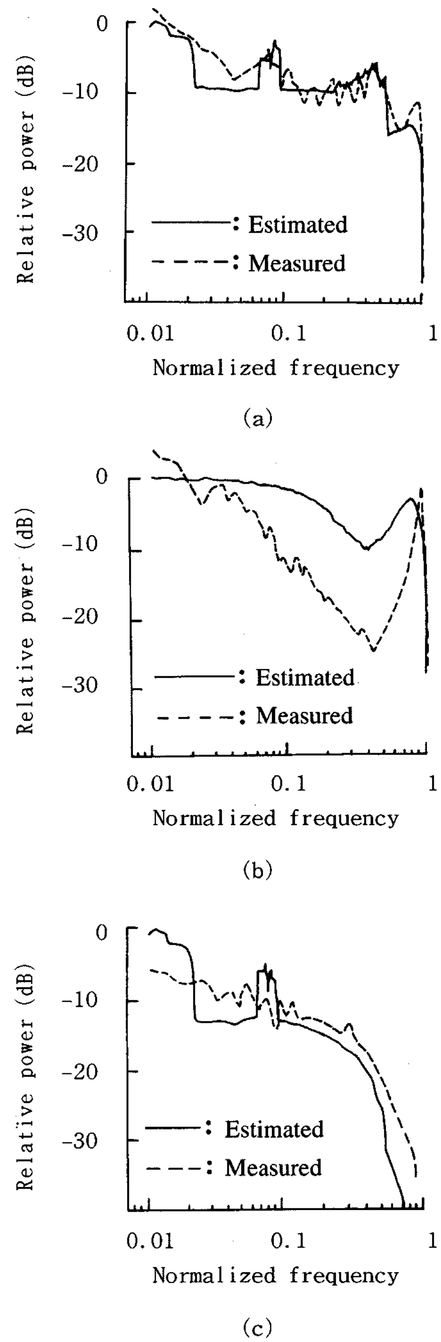

Fig. 9. Comparisons between estimated fading spectra and measured ones in (a) omnidirectional case; (b) parallel case; and (c) perpendicular case on Otsu Street.

under the condition that the dominant waves are suppressed by the radiation pattern of the receiving antenna. Two cases in Table III satisfy this condition. One is the parallel case on Otsu Street; the other is the perpendicular case on Hirokoji Street. A fairly good estimation result is given in the former, while the estimation error is larger for the latter. However, the estimation errors without considering the scattered waves are larger by 16 and 3 dB, respectively. Therefore, the consideration of the scattered waves is proved to be important, though the assumption of the cosine scattering pattern in the MERS is not necessarily suitable for how to take scattered waves into consideration.

B. Fading Spectrum

Figs. 8 and 9 show the comparisons between the estimated fading spectra and the measured ones on Hirokoji and Otsu Streets, respectively. In these figures, the vertical axes represent the relative power, while the horizontal axes represent the frequency normalized with twice the maximum Doppler shift fm.

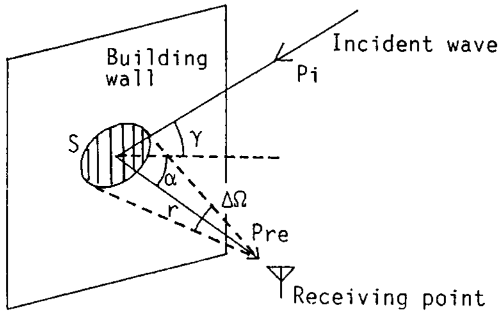

Fig. 10. Definition of scattering loss.

The agreement between the estimated curves and the measured ones is fairly good for all the cases on both test courses. A good agreement can be seen, especially for the tendencies of the variations with the radiation pattern. Therefore, the variation in the fading spectrum for the environmental conditions and a radiation pattern can be well estimated using the MERS.

Consequently, it is confirmed that the received power and the fading spectrum are well estimated. Therefore, the MERS including the propagation model proposed in this paper is proved to be applicable for estimating the received signal characteristics in mobile communication environments.

VI. Conclusion

The author has developed the MERS with which the received power and the fading spectrum in mobile communication environments can be estimated. The MERS has the advantage that environmental conditions and a radiation pattern can be taken into account for the estimation. The MERS aims at estimating the averaged characteristics of the signal received by a car antenna within an arbitrary region (estimation region) from 500 m to 1 km on an urban street. In the MERS, the averaged APD of wave arrival within the region is estimated; the received signal characteristics are estimated from both the averaged APD and the radiation pattern. For the estimation of the APD of wave arrival, a novel propagation model has been proposed in this paper. The model consists of an environmental model and a path model. The environmental model represents the statistical features of the surroundings around radio wave's propagation paths; the path model represents geometrical propagation paths from a transmitting point to a receiving point. The path model is obtained by modifying the ray theoretical model and can take scattered waves into account. The proposed model has the advantage that arbitrary environmental conditions can be easily considered due to the simplification of the environmental surroundings.

The received signal characteristics estimated using the MERS have been compared with the measured ones. From the comparison, the received power and the fading spectrum have found to be well estimated. Therefore, it is proved that the MERS is an effective way of estimating the received signal characteristics in mobile communication environments. Furthermore, it is confirmed through the development of the MERS that an APD of wave arrival should be considered when estimating the received signal characteristics and that the consideration of the scattered waves is important.

In the future, the MERS will be a very useful tool especially in designing car antennas conformed to a car body and mounted in a car cabin.

Appendix
Calculation of Scattering Loss

Scattering power density Pre at a receiving point can be calculated using (5). In the calculation, the author assumes that the scattering power is reradiated in a cosine scattering pattern

$$Pre = \frac{\rho \cdot Pi \cdot \cos\gamma \cdot S \cdot \cos\alpha}{4\pi r^2} \tag{5}$$

where Pi is the incoming power density at the center of the area S on the wall of interest, γ is the incoming angle to the wall, S is the area on the wall corresponding to the unit solid angle in the direction from the receiving point to the scattering point, α is the scattering angle, and r is the distance from the scattering point to the receiving point, as shown in Fig. 10. In addition, ρ is the scattering coefficient and the author empirically used the value of 0.16 in this paper. The relation between S and unit solid angle $\Delta\Omega$ can be expressed following equation:

$$S = \frac{r^2 \Delta\Omega}{\cos\alpha}. \tag{6}$$

Substituting (6) into (5), the following is obtained:

$$Pre = \frac{\rho \cdot Pi \cdot \cos\gamma \cdot \Delta\Omega}{4\pi}. \tag{7}$$

Since the scattering loss Ls is defined as a ratio of Pre to Pi, Ls can be expressed as follows:

$$Ls = 10 \log \frac{4\pi}{\rho \cdot \cos\gamma \cdot \Delta\Omega} \quad \text{(dB)}. \tag{8}$$

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