Spatio-Temporal Channel Characterization in a Suburban Non Line-of-Sight Microcellular Environment

Jun-ichi Takada, *Member, IEEE*, Jiye Fu, Houtao Zhu, *Associate Member, IEEE*, and Takehiko Kobayashi, *Member, IEEE*

***Abstract*—This paper reports a spatio-temporal channel characterization of a suburban non line-of-sight microcellular environment in which azimuth-delay profiles obtained by the experiment are compared with ray-tracing simulation. The results are statistically treated step by step to extract model parameters in order to characterize the spatio-temporal channel. The experimental results we obtain are used to improve the accuracy of the simulation process. We are able to obtain a very good agreement between the simulation and the experiment, with the exception of the exponential decay of the delay profile. The results presented in the paper can be directly used to implement the stochastic spatio-temporal channel model, based on the deterministic ray-tracing simulations.**

***Index Terms*—Land mobile radio propagation factors, multipath chanels, ray tracing.**

I. Introduction

THE RECENT progress of the high data-rate wireless communication systems, such as IMT-2000 and IEEE 802.11, is obvious. From the viewpoint of the radiowave propagation, however, these systems exhibit the following disadvantages.

- In order to increase the data rate, the broadband channels are necessary. The carrier frequency needs to be increased for this purpose. However, both the free space path loss and the diffraction loss increase according to any increase in the frequency.
- The channel spreading factor, $f_d\tau_d$, where f_d is the maximum Doppler spread and τ_d is the maximum delay spread, also increases as a function of the carrier frequency. This results in intersymbol interference for single carrier systems and in difficulties for carrier tracking in multicarrier systems.
- Due to an increase in the path loss, the cell size needs to be decreased to the microcell or the picocell. Co-channel interference is more difficult to control in the microcellular environment.

The first and third problems are related to the space domain properties of the channel, whilst the second problem is related to the time domain properties of the channel. Various kinds of the solutions have been proposed to solve these problems, including the use of adaptive equalizers, adaptive array antennas for beamforming or null-forming or diversity, interference cancelers and multiuser detectors, code division multiple access (CDMA) and code division multiplex (CDM), frequency hopping, orthogonal frequency division multiplex (OFDM) and multicarrier transmission, adaptive modulations, etc. The relative performances of these technologies much depend on the spatial and temporal characteristics of the channel and, therefore, realistic models of the channels are needed [1], [2]. The authors have been working on the spatio-temporal channel characterization by using a combination of the deterministic ray-tracing approach and the statistical random phase approach [3]. This hybrid approach has been examined in comparison with various experimental results [4]–[11]. The results have shown that the dominant channel properties, such as the path loss, the azimuth and the delay of the principal waves exhibit a good degree of agreement between the experiment and simulation. The delay spread, however, cannot be modeled well, which is mainly due to the presence of nonspecular reflections and of random scattering [10]. The authors have been independently studying ways to consider the effect of random scattering on the ray-tracing simulation [12], [13].

This paper proposes an alternative approach in which the statistical properties of the channel, based on the experimental results, are incorporated into the ray-tracing simulation in order to obtain a more detailed and realistic channel model. The frequency of 8.45 GHz has been chosen, which had been a candidate spectrum for the 4G mobile communication system, and the high gain anntenna with the narrow beamwidth is easy to realize. This paper focuses on the extraction of the statistical model parameters from the azimuth-delay profile and a detailed stochastic modeling of the channel will be presented in a separate paper.

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J. Takada is with the Department of International Development Engineering, Tokyo Institute of Technology, Tokyo 152-8552, Japan (e-mail: takada@m.ieice.org

J. Fu was with the Department of Information Processing, Tokyo Institute of Technology, Yokohama, Japan. He is now with the KDDI Corporation, Tokyo 163-8003, Japan (e-mail: ke-fu@kddi.com).

H. Zhu was with the Department of Information Processing, Tokyo Institute of Technology, Yokohama, Japan. He is now with the Nokia Research Center, Tokyo 100-0014, Japan (e-mail: houtao.zhu@nokia.com).

T. Kobayashi was with the YRP Mobile Communication Key Technology Research Laboratories Company Ltd., Yokosuka, Japan. He is now with the Department of Information and Communication Engineering, Tokyo Denki University, Tokyo 101-8457, Japan (e-mail: koba@c.dendai.ac.jp).

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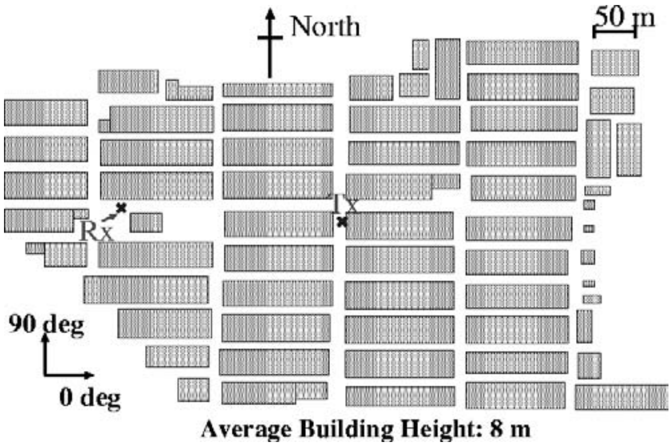

Fig. 1. The Yokosuka Highland microcellular environment.

TABLE I
ELECTRICAL PARAMETERS USED IN THE RAY-TRACING SIMULATION

	ϵ_r	σ [s/m]
Concrete [15]	5.5	0.023
Foliage [10]	1.2	0.0003
Ground [16]	15.0	1.3
Metal	– – –	∞

II. THE ENVIRONMENT UNDER CONSIDERATION

Fig. 1 shows a map of Yokosuka Highland area, which is the environment under consideration. This is a residential area with predominantly wooden houses of 8 m average height and is considered to be a typical suburban microcellular environment of size 600×600 m^2. The traffic was very light and the environment was considered to be static throughout the experiments. In this paper, a non line-of-sight (NLOS) transmitter and receiver shown in Fig. 1 are considered. The distance between the transmitter and the receiver was 219 m. As a transmitter antenna, simulating the mobile station (MS), a vertically polarized omnidirectional half wave sleeve dipole was set at the height of 2.7 m. At the receiving point, corresponding to the base station (BS) , the azimuth-delay profile was taken. This was measured by rotating a vertically polarized parabolic antenna, which had azimuthal and elevational beamwidths of about 4°, at an azimuth step of 4° and was set at a height of 4.4 m. At each azimuth step, the delay profile was measured by using a delay profile measurement system [14]. At a center frequency of 8.45 GHz and with a chip rate of 50 Mcps, a seven stage M sequence with a dynamic range of 42 dB was transmitted. A correlation receiver was used to output the delay profile.

The electric parameters used in the ray-tracing simulation are presented in Table I.[1] The wooden houses are modeled by the confrete, as the surface of the houses are covered by the concrete-like paint. To compare with the experimental results, the directivity of the antenna and the autocorrelation of the pseudorandom noise (PN) sequence were convolved with the result of the ray-tracing simulation. Therefore, the path gain includes the antenna gain.

[1]In reality, the choice of the electrical parameters is rather insensitive to the ray-tracing result.

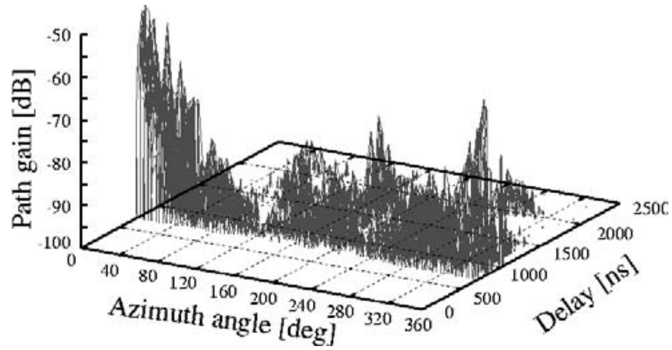

Fig. 2. Azimuth-delay profile: Experiment.

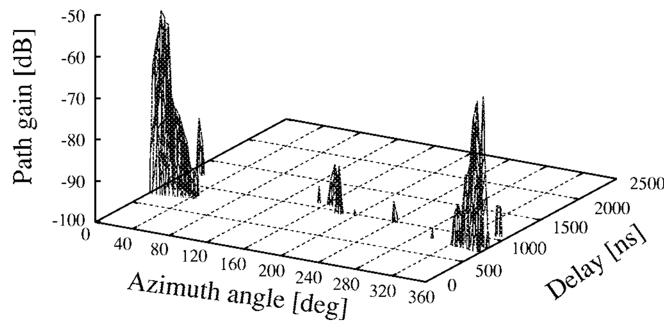

Fig. 3. Azimuth-delay profile: Simulation.

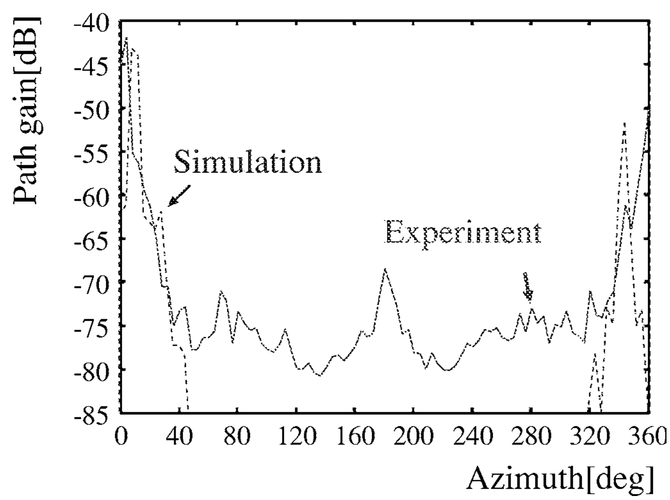

Fig. 4. Azimuth profile. Solid line: Experiment. Dotted Line: Simulation.

III. EXTRACTION OF SPATIO-TEMPORAL CHANNEL PARAMETERS

A. Azimuth-Delay Profile

The experimental and the simulation results of the azimuth-delay profile are shown in Figs. 2 and 3, respectively. Comparing together both results, the ray-tracing simulation can be seen to predict the arrival of strong signals from the front and the back. On the contrary, however, the delay spread could not be estimated well by the simulation.

B. Azimuth Profile

Azimuth profiles were obtained by summing up the power of azimuth-delay profiles (Figs. 2 and 3) with respect to the delay time. Fig. 4 shows the azimuth profiles obtained from the experiment as the solid line and from the simulation as the dotted

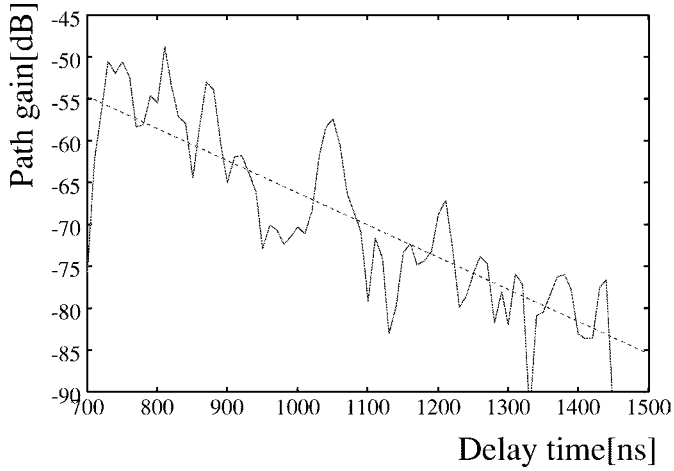

Fig. 5. Delay profile of forward arrival waves: Experiment.

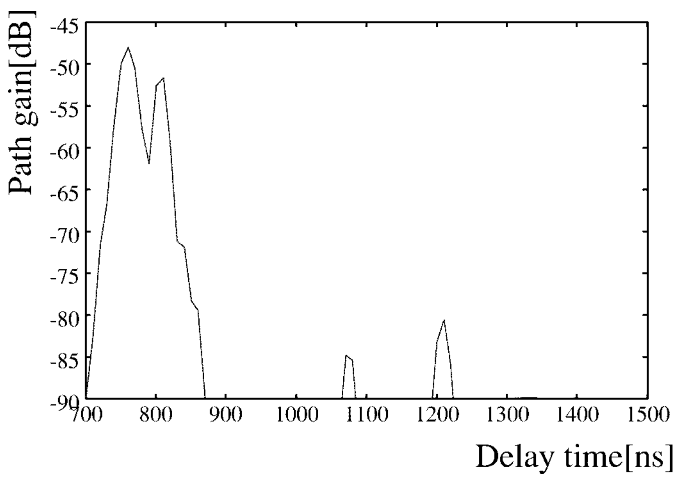

Fig. 6. Delay profile of forward arrival waves: Simulation.

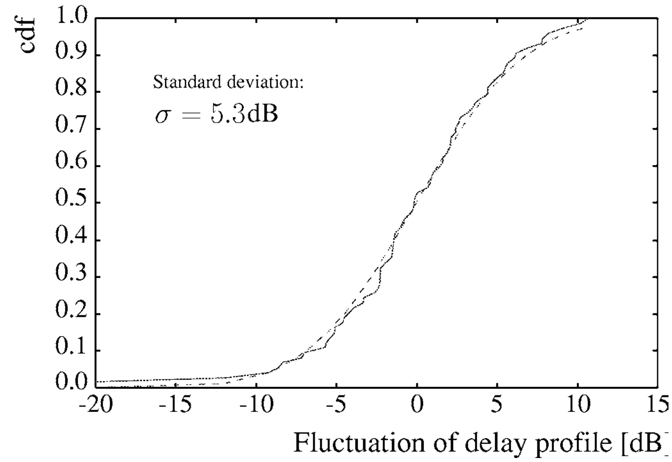

Fig. 7. CDF of the fluctuation component of the experimental delay profile from its exponential fit for forward arrival waves: Experiment.

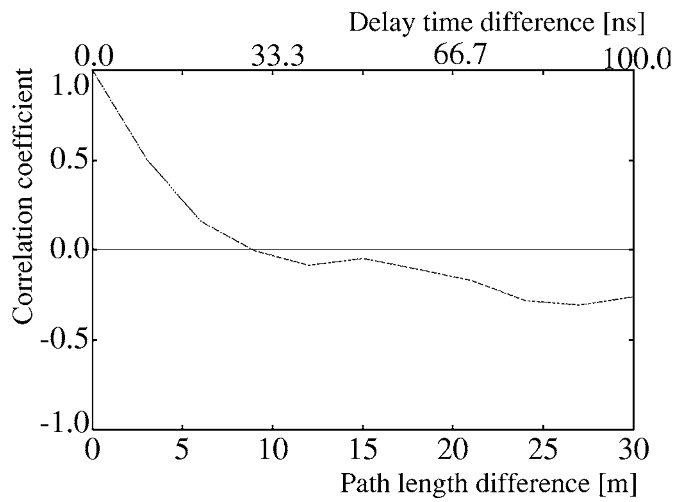

Fig. 8. Autocorrelation of the fluctuation component of the experimental delay profile from its exponential fit for forward arrival waves: Experiment.

line. From Fig. 4, the forward arrival waves within the range from -40° to 44° are in agreement for both data sets with respect to the level and the shape of the profile. The experimental profile has the floor level of about 30 dB below from the peak, but this level is low enough so that its effect on the transmission property is negligibly small.

C. Delay Profile for the Forward Arrival Waves

For the forward arrival waves (-40° to -44°), the delay profiles are obtained by summing up the azimuth-delay profiles with respect to the azimuth. The experimental result is shown in Fig. 5, and the simulation result is shown in Fig. 6. The experimental result exhibits an exponential decay. The results of least squares fitting are shown as the dashed line in Fig. 5. The function is expressed as

$$P(\tau) = -0.038\tau - 28.6 \tag{1}$$

where P is the path gain in dB, and τ is the delay time in ns.

The ray-tracing simulation can predict accurately the first two peaks in the delay profile. However, the exponential decay of the profile cannot be accurately predicted. The problem here seems to be due to incomplete modeling of the effect of random scattering in the ray-tracing simulation. If, however, the gradient of this exponential function can be determined by some independent means, the ray-tracing results can be extrapolated to predict accurately the delay profile.

The cumulative distribution function (CDF) of the fluctuation component of the experimental data from its exponential fit is shown in Fig. 7. This fluctuation component can be very accurately approximated by a log-normal distribution with a standard deviation of 5.3 dB. In the ray-tracing simulation, waves with a long delay time cannot be predicted. Instead, their statistical properties are used for the extrapolation.

The autocorrelation of this fluctuation component is presented in Fig. 8. The correlation decreases monotonously, with a correlation distance and a time at a correlation coefficient of 0.5 of about 3 m and 10 ns, respectively. Considering the resolution of the delay profile, which is equal the chip duration 20 ns, the fluctuation is modeled as uncorrelated, just as in the wide sense stationary uncorrelated scattering (WSSUS) model [17].

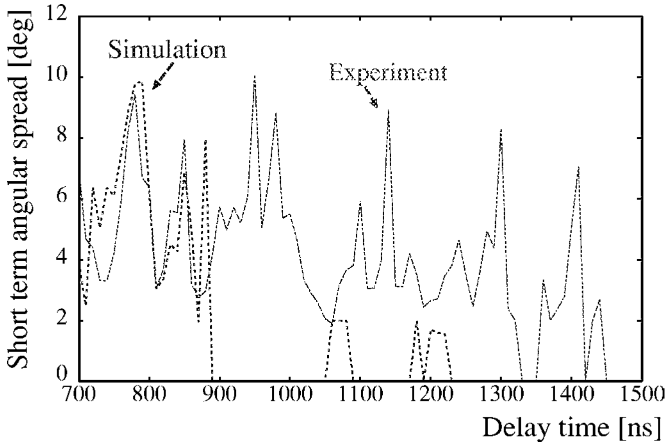

Fig. 9. Short-term AS for forward arrival waves. Solid line: Experiment. Dotted Line: Simulation.

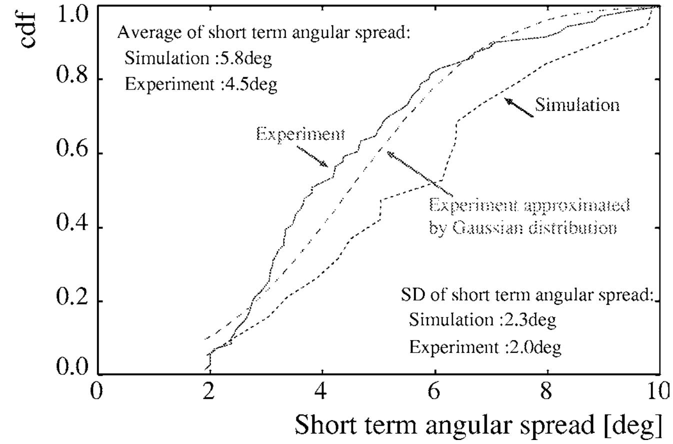

Fig. 10. CDF of the short-term AS for forward arrival waves. Solid line: Experiment. Dotted Line: Simulation.

D. Short-Term Azimuth Spread (AS) for Forward Arrival Waves

Fig. 4 showed the azimuth profile averaged over the delay time. Here, we focus on the short-term azimuth profiles, which are obtained every 10 ns. The short-term AS for the forward arrival waves, σ_{φ}, is defined as (2)[2]

$$\sigma_{\varphi}(\tau) = \sqrt{\langle \varphi^2(\tau) \rangle - \langle \varphi(\tau) \rangle^2} \tag{2}$$

where $\langle \cdot \rangle$ is the average of the φ weighted by the power for a fixed delay time, τ. At each delay time, the threshold level is set to be 30 dB below the peak in the profile in order to calculate the short-term AS in (2).

Fig. 9 shows the resultant sort term angular spread. The solid line indicates the experimental result and the dotted line indicates the result of the simulation. Both results agree well within the range 740 ns–860 ns in which the ray-tracing simulation is known to predict the delay profile accurately (as shown in Fig. 6). The experimental result are observed to exhibit the same properties for a larger delay time. Therefore, this behavior can be used for an extrapolation of the angular profile beyond the range in which the simulation can predict the delay profile.

Fig. 9 indicates that the variation of the short-term AS can be modeled as a stationary process. To characterize this stationary process, the CDF of the short-term AS is shown in Fig. 10. The solid line indicates the experimental result and the dotted line indicates the simulation result. It is noted that the simulation result is obtained within a range of delay times from 700 ns to 880 ns. Although the distribution functions of the experiment and the simulation look slightly different, their average and their standard deviation are both in agreement. A Gaussian distribution has been used as an approximation in the figure, although the most appropriate distribution function to use is still under consideration.

Fig. 11 shows the autocorrelation function of the short-term AS. The solid line indicates the experimental result and the dotted line indicates the simulation result. In a similar way to Fig. 8, the correlation decreases monotonously. The correlation distance at a correlation coefficient of 0.5 is about 2 m for the experimental data and about 5 m for the simulation. The correlation distance is smaller using the experimental data, since random scattering is not taken into account in the simulation. As in Fig. 8, considering a chip duration of 20 ns which corresponds to a distance of 6 m, the short-term angular spread is also modeled as uncorrelated. It is noted that the correlation distances for Figs. 8 and 11 are comparable and that, therefore, these two fluctuations seem to be related to each other.

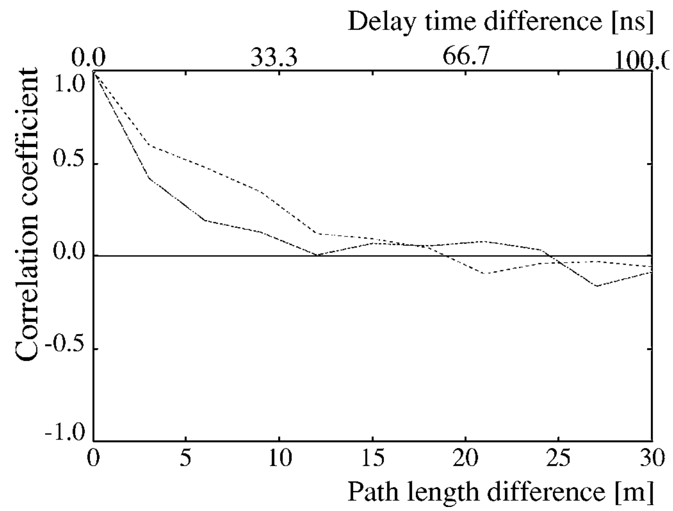

Fig. 11. Autocorrelation of the short-term AS for forward arrival waves. Solid line: Experiment. Dotted Line: Simulation.

E. Cross Correlation Between Fluctuation Component of the Experimental Delay Profile From its Exponential Fit and the Short-Term Azimuth Profile for Forward Arrival Waves

Since the the fluctuation component from the exponential function of the delay profile and the short-term azimuth profile for the forward arrival waves have similar correlation lengths, they would seem be some relationship between them.

We propose a Nakagami–Rice fading model for the short-term azimuth profile, as shown in Fig. 12. This is composed of a stable strong signal component plus a weak scattered

[2]More rigorous definition of the angular spread has been proposed in [18], and [19], based on the spatial spectrum. The authors use (2) for simplicity, since the error from the rigorous value is within 2.5% in this paper, which is negligibly small.

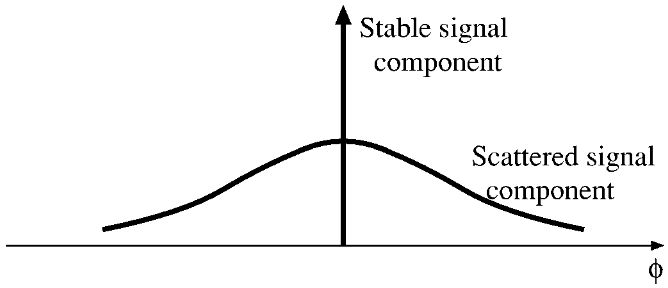

Fig. 12. Nakagami–Rice fading model for the short-term azimuth profile.

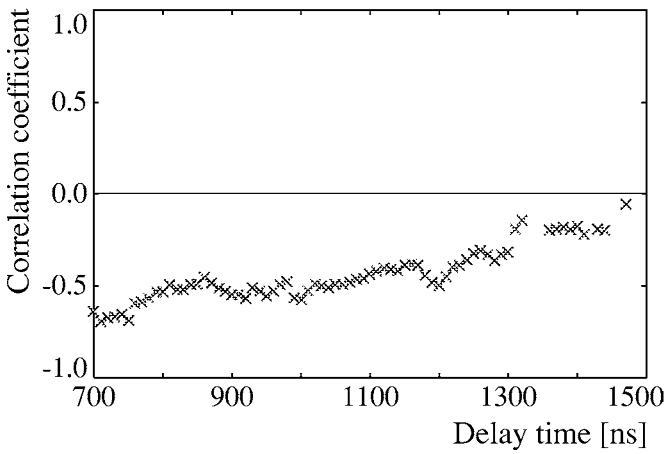

Fig. 13. Cross correlation between fluctuation component of the experimental delay profile from its exponential fit and the short-term azimuth profile for forward arrival waves: experiment.

signal component. The scattered signal component is assumed to be stationary. Under these assumptions, the power increases and the AS decreases when the stable signal component is large, i.e., there is a negative correlation between these parameters.

To evaluate this model, the cross correlation is calculated between the fluctuation component of the experimental delay profile from its exponential fit and the short-term azimuth profile for the forward arrival waves, which is defined as

$$\rho_{P\Delta\varphi} = \frac{\langle (P(\tau) - \langle P(\tau)\rangle)(\Delta\varphi(\tau) - \langle \Delta\varphi(\tau)\rangle)\rangle}{\sqrt{\langle (P(\tau) - \langle P(\tau)\rangle)^2\rangle \langle (\Delta\varphi(\tau) - \langle \Delta\varphi(\tau)\rangle)^2\rangle}} \quad (3)$$

where $\langle\cdot\rangle$ is the sample average within the given time window, $P(\tau)$ is the fluctuation component from the exponential function at a delay time, τ, in dB and $\Delta\varphi(\tau)$ is the short-term angular spread at a delay time, τ, in degree. Fig. 13 shows the cross correlation with a time window of 200 ns for the experimental data. It is clear from Fig. 13 that the fluctuation component of the delay profile and the short-term AS are negatively correlated. This result suggests that the proposed Nakagami–Rice fading model can be used successfully to model the short-term azimuth profile.

F. Summary of the Method of Extraction of the Model Parameters

The procedure to extract the model parameters is summarized as a flow chart in Fig. 14. The azimuth-delay profile is taken as the original data. The azimuth profile is first calculated to extract the forward arrival waves. Next, the delay profile for the forward arrival waves is approximated as an exponential function together with a fluctuation component as a stationary log-normal distribution. At the same time, the short-term angular spread is approximated as the stationary normal distribution.[3] The fluctuation component of the delay profile and the short-term AS are negatively correlated. To model this cross correlation, the Nakagami–Rice model is proposed to model the short-term azimuth profile. In this model, the average power is assumed decrease exponentially and the fluctuation component modeled as follows. The stable signal is modeled as a log-normal distributed stationary process with respect to the delay time. The scattering components are also modeled as stationary processes with respect to the delay time.

The backward arrival waves can be modeled in the same manner, although the results are not included in this paper. The difference between the backward and the forward arrival waves is that no strong stable component is observed in the short-term azimuth profile of the backward arrival waves. Therefore, the Rayleigh model can be used instead of the Nakagami–Rice for the modeling.

G. Extraction of Model Parameters From Ray-Tracing Simulation Result

The results presented in this paper have shown that the model parameters extracted from the ray-tracing result are in good agreement with those from the experiment. It is concluded that the extraction of model parameters is possible using the results of the ray-tracing simulation alone. Nevertheless, the delay profile cannot be well predicted by the ray-tracing simulation and, therefore, a method is required to predict the exponential decay of this profile. Only the experimental results are applied in this paper and the prediction of the decay in the ray-tracing is left for future study.

IV. Conclusion

This paper presents a procedure to model the spatio-temporal channel for the NLOS suburban microcellular environment. This paper mainly focuses on the extraction of the model parameters. The procedure cannot only be applied to the experimental data but also applicable to the simulation results. The only unsatisfactory aspect of the modeling is the prediction of the exponential decay of the delay profile in the simulation. It is not a simple task to obtain the spatio-temporal channel data by using a delay profile measurement system and a parabolic antenna, since large-scale facilities are necessary. The results of this paper suggest that the stochastic spatio-temporal channel modeling can be achieved by applying the procedure presented in this paper to extract the model parameters.

This paper, however, does not present details on the implementation of stochastic spatio-temporal channel modeling. Stochastic modeling techniques similar to the approaches of Karasawa *et al.* [20], [21] would need to be developed in the future, based on the results of this paper.

[3] If the Nakagami–Rice model is valid, the distribution function is given explicitly. In this case the stable signal varies according to a log-normal distribution.

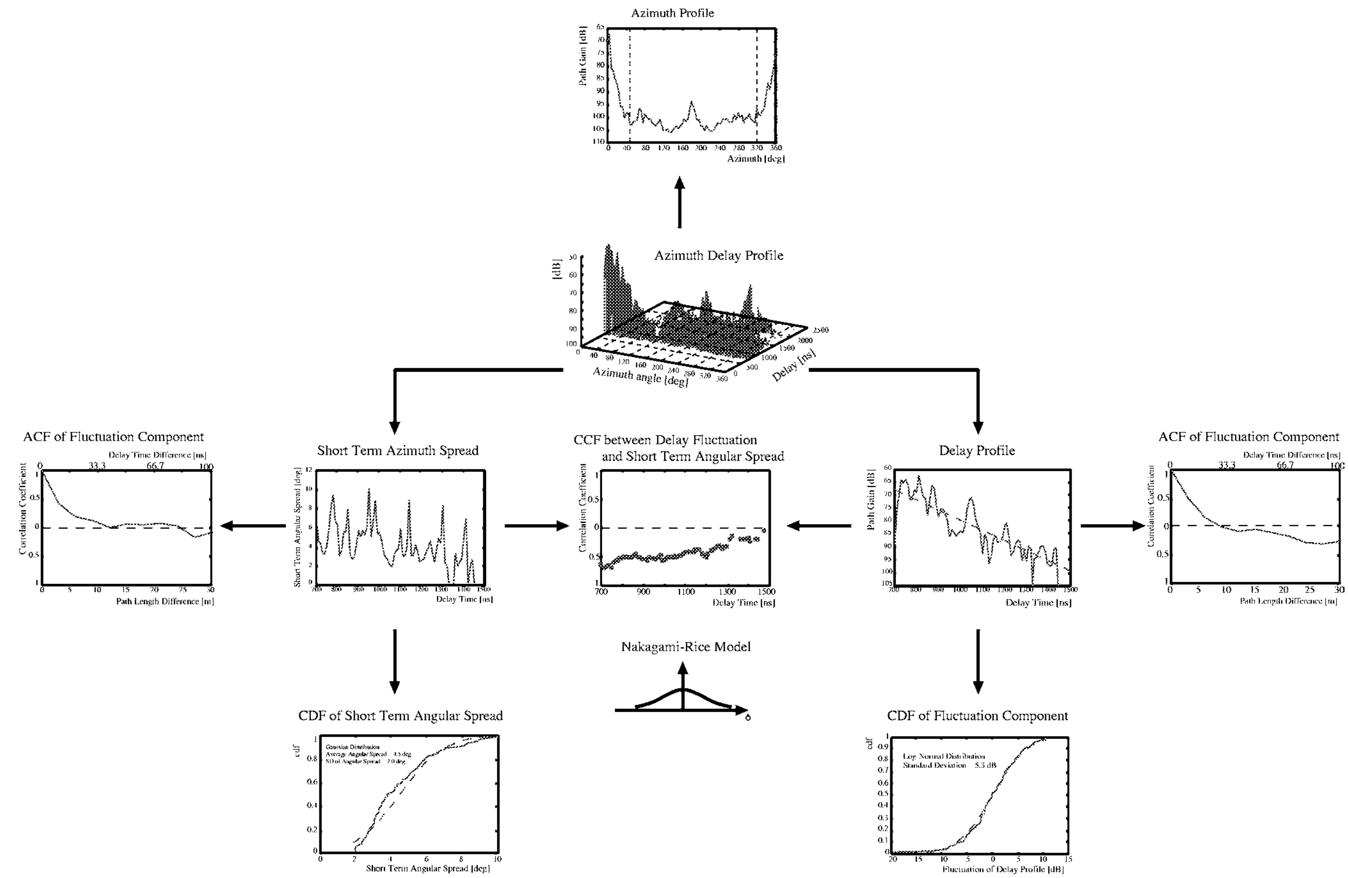

Fig. 14. Flow chart showing the procedure for the extraction of model parameters from azimuth-delay profile.

Line-of-sight (LOS) environments have also been considered and the results of these measurements will be presented in future.

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Jun-ichi Takada (S'89–M'89) was born in Tokyo, Japan, in 1964. He received the B.E., M.E., and D.E. degrees from Tokyo Institute of Technology, Japan, in 1987, 1989, and 1992, respectively.

From 1992 to 1994, he has been a Research Associate at Chiba University, Chiba, Japan. From 1994, he has been an Associate Professor at Tokyo Institute of Technology, Tokyo, Japan. His current interests are mobile propagation and channel modeling, array signal processing, and numerical simulation of waves.

Mr. Takada received the Excellent Paper Award and Young Engineer Award from IEICE, Japan, in 1993 and 1994, respectively. He is a member of the IEICE, ACES, SIAM and AGU.

Jiye Fu was born in China, on November 25, 1972. He received the B.E. and M.E. degrees from Tokyo Institute of Technology, Tokyo, Japan, in 1999 and 2001, respectively.

He engaged in the spatio-temporal channel characterization in microcellular and picocellular environments, during his master course study. He is currently working at KDDI Corp., Tokyo, Japan.

Houtao Zhu (S'98–A'00) was born in Shanghai, China, in l968. He received the B.E. degree in communication engineering from Shanghai Jiao Tong University, Shanghai, China, in 1991, the M.E. degree in telecommunications from Asian Institute of Technology, Bangkok, Thailand, in 1996, and the D.E. degree in information processing from Tokyo Institute of Technology, Tokyo, Japan, in 2000.

He is now working as a Research Engineer in Nokia Research Center, Tokyo, Japan. His main research interests are propagation prediction modeling, wireless channel modeling, smart antennas, and wireless communications.

Dr. Zhu is a member of the IEICE.

Takehiko Kobayashi (M'86) received the B.E., M.E., and Ph.D. degrees in electrical engineering from the University of Tokyo, Tokyo, Japan, in 1978, 1980, and 1983, respectively.

He joined Nippon Telegraph and Telephone, Tokyo, Japan, in 1983, and was engaged in research on wireless communication systems. He was a Guest Scientist at National Bureau of Standards (now NIST), Boulder, Colorado, in 1986. From 1998 to 2001, he was with YRP Key Tech Labs, Yokosuka, Japan, which focuses on fourth-generation mobile communication systems. Currently, he is a Professor at the Department of Information and Communication Engineering, Tokyo Denki University, Tokyo, Japan. His research interests include network architecture, teletraffic, IP transmission, and radio propagation for the future mobile communications.

Dr. Kobayashi received the Excellent Paper Award from the IEICE, in 2001.