Modeling of Wideband DS-SS Signaling over Multipath Fading Channels

*Chankil Lee, *Youngsik Jeon, and **Deuk-Su Lyu

Abstract

A mobile propagation characteristics for wideband DS-SS (Direct Sequence-Spread Spectrum) signal is presented. Existing narrowband model is extended for the wideband pulse with an arbitrary shape. The received DS-SS signal in the frequency domain is the transfer function of the propagation channel weighted by the inverse Fourier transform. In this proposed method, received signal spectral density, instantaneous waveform, and Doppler spectrum of DS-SS signal via either Rayleigh or Rician channel can be obtained easily. Simulation results match well with both simulated theoretical fading statistics and classical theory. As expected, the extraction of chip timing in Rician fading shown to be more tractable than Rayleigh fading.

I. Introduction

The most widely employed analysis of the fading phenomenon are predicted on the assumption that radio frequency carrier is either unmodulated or that the modulation bandwidth is small enough that amplitude and phase characteristics of the transmission medium are constant over the signal bandwidth, which is known as frequency-nonselective fading. Under these conditions, in the presence or absence of a direct specular path from the transmitter and receiver, the fading statistics are classically found to be Rayleigh or Rician, respectively. In wideband transmission, the wave arriving at the mobile station at some frequencies within the band becomes stronger, while at other frequencies it becomes weaker, which is known as frequency-selective fading [1]. The variation of the received signal level for wideband transmission is entirely different from that for narrowband transmission [2]. Consequently, the propagation characteristics in a wideband transmission must be clarified to evaluate various digital communication systems and select system parameter.

A geometric propagation simulation model is used for simulation of direct sequence pseudonoise signaling with omnidirectional and directional antennas in the dense scatter mobile environment [3]. This model is first validated for narrowband signals by a direct comparison of both simulated signal strength statistics with cumulative density function (CDF) and simulated diffuse Doppler spectra with classical theory. The model is then used to quantify the mitigation of the Rayleigh fading effect by the standard deviation of the received signal power as a function of the ratio, chip period/rms delay spread. Rayleigh fading reduction effect or frequency diversity effect is also showed by the simple analysis [4] measurement [5], respectively.

This paper presents a generalized approach to clarify the fundamental propagation characteristics of the received signal for narrowband and wideband transmission via either Rayleigh fading or Rician fading channel. Based on the geometrical propagation model and assumptions of the earlier theoretical treatment [6], a general expression for the transfer function of the Rayleigh channel is derived and extended to Rician channel at first. For the characteristics of the received DS-SS signal, the transfer function of the propagation channel weighted by the spectral shape of pulse is derived. Instantaneous received signal is then given by the inverse Fourier transform. Finally, the received signal spectral density, instantaneous waveform, and Doppler spectrum of DS-SS signal via Rayleigh and Rician channel are examined by simulations and compared with both theoretical fading statistics and classical theory.

II. Propagation Model and Results

2.1 Propagation Model

The complex impulse response of the propagation channel at mobile location R is modeled by [3]

$$h(R,t)=\sum_n \alpha_n(R)\,\delta(t-\tau_n(t)),\quad \text{where}\quad \alpha_n(R)=\frac{A_n e^{j\theta_n}}{4\pi r_n/\lambda}.$$

* Department of Electronics Engineering, Hanyang Univ.
** Department of Mobile Communication Technology, ETRI
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Here, propagation attenuation constant of nth path, $\alpha_n(R)$, is a function of reflection coefficient A_n, the distance from nth scatterer to the antenna r_n, the static phase shift of the nth scatterer ϕ_n, and wavelength λ as shown in Figure 1 Multipath delay, $\tau_n(t)=(x_n+r_n)/C$, is function of x_n, horizontal distance from the left boundary of the scatterer constellation to the nth scatterer.

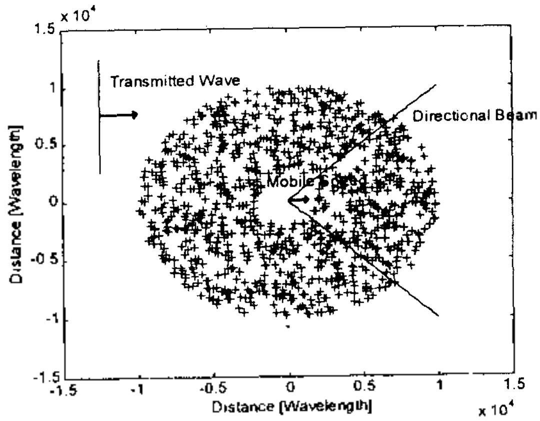


Figure 1. Scatterers model in mobile propagation channel

2.2 Rayleigh Fading Channel

In order for the narrowband signal to exhibit the characteristic Rayleigh fading, the antenna track must span enough wavelengths to produce a large quantity of uncorrelated fading samples. It was found that a track length of 800 wavelengths was sufficient to produce smooth statistical averages.

2.2.1 Narrowband Signaling

For an unmodulated carrier signal, $s(t)=e^{j2\pi f_c t}$, the received signal is expressed by

$$r(R,t)=s(t)*h(R,t)=e^{j2\pi f_c t}\sum_n \alpha_n(R)e^{-j2\pi f_c \tau_n(t)}.$$

The envelope of received signal at the distance R is then given by

$$r(R)=\sum_n \alpha_n(R)e^{-j2\pi f_c \tau_n(t)}, \text{ where } \alpha_n(R)=\frac{A_n e^{j\phi_n}}{4\pi r_n/\lambda_c} \text{ and } \lambda_c=C/f_c.$$

Figure 2 and 3 show the signal strength, CDF statistics, and Doppler spectrum for omnidirection and direction antennas reception, respectively. As shown in the Figures, the model used in the simulations reflects well Rayleigh

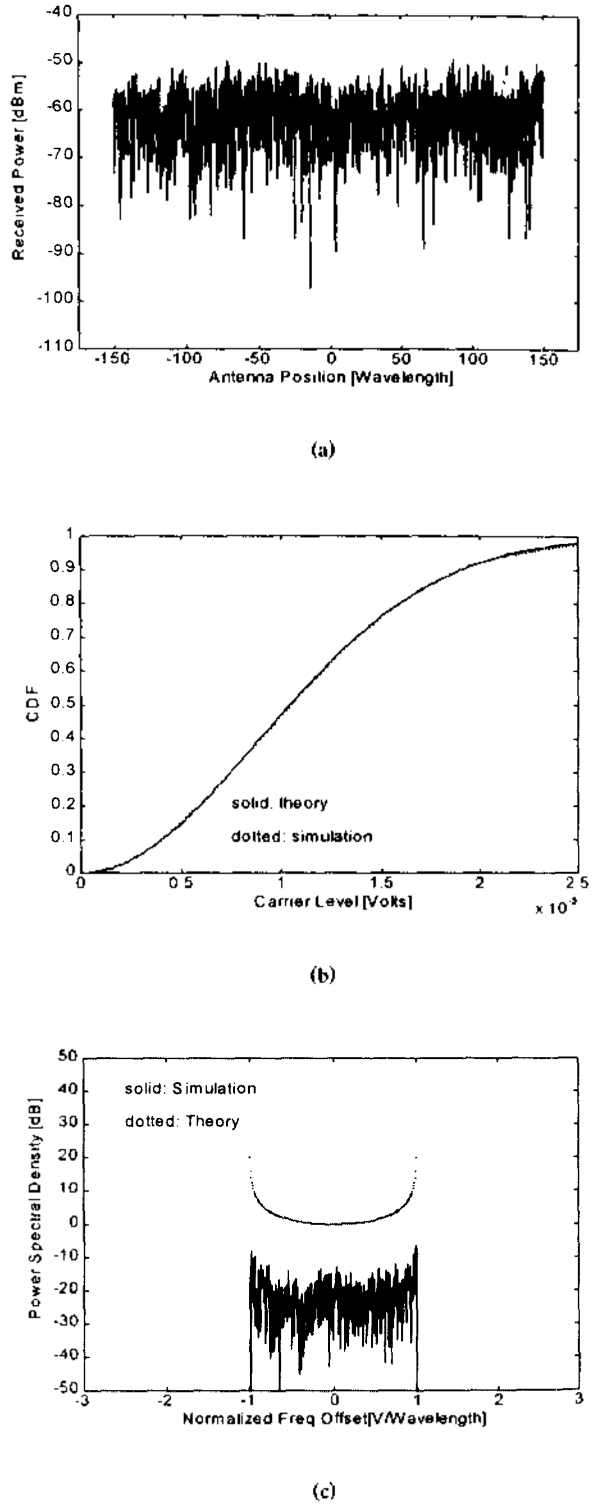
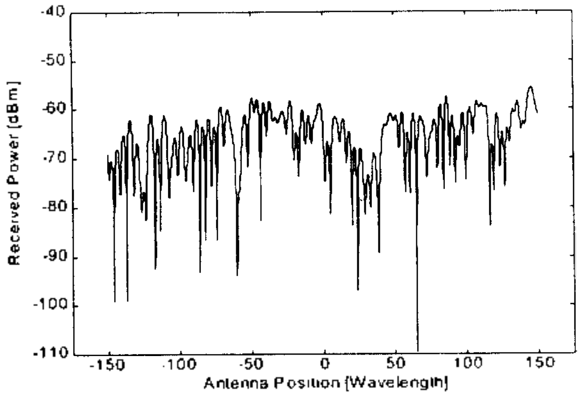


Figure 2. Simulated Rayleigh fading signal, unmodulated carrier, omnidirectional antenna; (a) received signal envelope, (b) CDF statistics, (c) diffuse Doppler spectrum.



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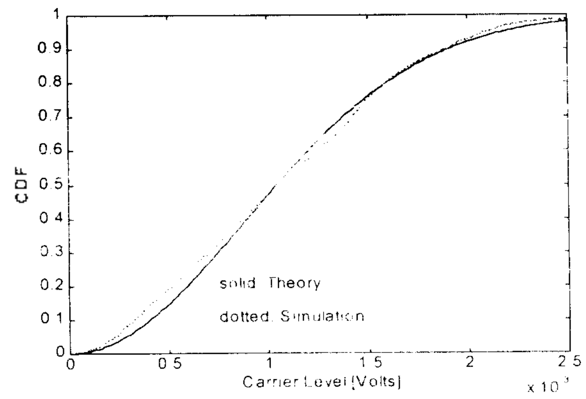

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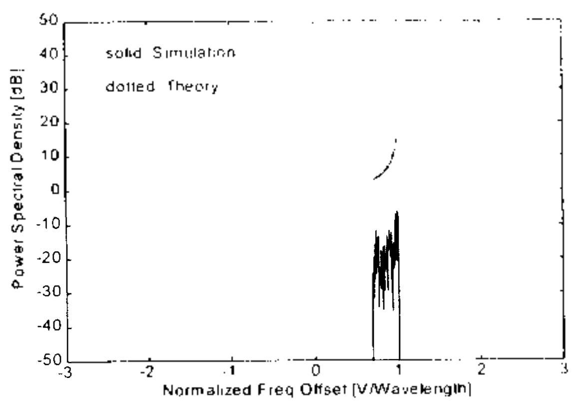

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Figure 3. Simulated Rayleigh fading signal, numodulated carrier, directional antenna ; (a) received signal envelope, (b) CDF statistics, (c) diffuse Doppler spectrum.

statistics. The coarse correspondence in directional case owes to the reduced quantity of uncorrelated samples. The Doppler spectrum was obtained by inverse Fourier transform of hamming windowed complex received signal and shown to be matched well with theoretical prediction in [6]. Only positive offsets in the directional case come from that beam pattern of antenna is in moving direction of mobile.

2.2.2 Wideband Signaling

For the wideband transmission case, consider DS-SS signal with a spectrum of

$$S(\omega_k) = |S(\omega_k)| e^{j\theta_k}, \quad k = 1, \ldots, 2\pi/L.$$

The transfer function of Rayleigh channel at $f_k = C/\lambda_k$ is given by

$$H(R, \omega_k) = \sum_n a_n(R, \omega_k) e^{-j2\pi r_n(t)C/\lambda_k}, \text{ where } a_n(R, \omega_k) = \frac{A_n e^{j\phi_n}}{4\pi r_n/\lambda_k}.$$

The frequency response of received DS-SS signal at distance R is then given by

$$R(R, \omega) = \sum_k H(R, \omega_k) S(\omega_k)$$

$$= \sum_k \sum_n a_n(R, \omega_k) |S(\omega_k)| e^{-j[2\pi r_n(t)C/\lambda_k - \theta_k]}.$$

The received signal can be obtained by inverse Fourier transform

$$r(R, t) = F^{-1}\{R(R, \omega)\}.$$

For the simulations, 100% raised cosine shaped chip pulse, the delay spread (Δ) of 5108λ for omnidirectional and 4432λ for directional antenna, were used. Figure 4 shows the received signal power for the chip duration of 0.2 * Δ and typical spectral power density of received signal at mobile location 100λ. This result indicates the ant-fading effect of wideband signaling. Figure 5 indicates that the extraction of chip timing from complex received signal seems to be difficult. Figure 6 show standard dB deviation as changing bandwidth of chip pulse. This result indicates that optimum chip rate can be determined for a specific channel characteristics described by delay spread.

2.3 Rician Fading Channel

Rician fading results from the multipath signals from many diffuse scatters in the presence of direct signal from buildings containing metallic components or structure gui-

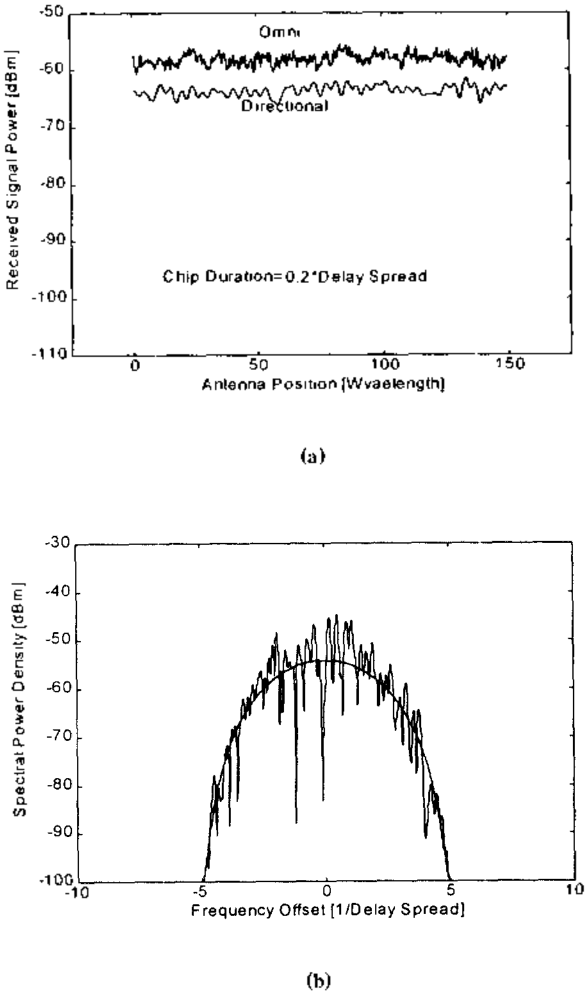


Figure 4. Simulated Rayleigh fading signal at mobile location 100λ, DS/SS; (a) received signal envelope, (b) spectral power density.

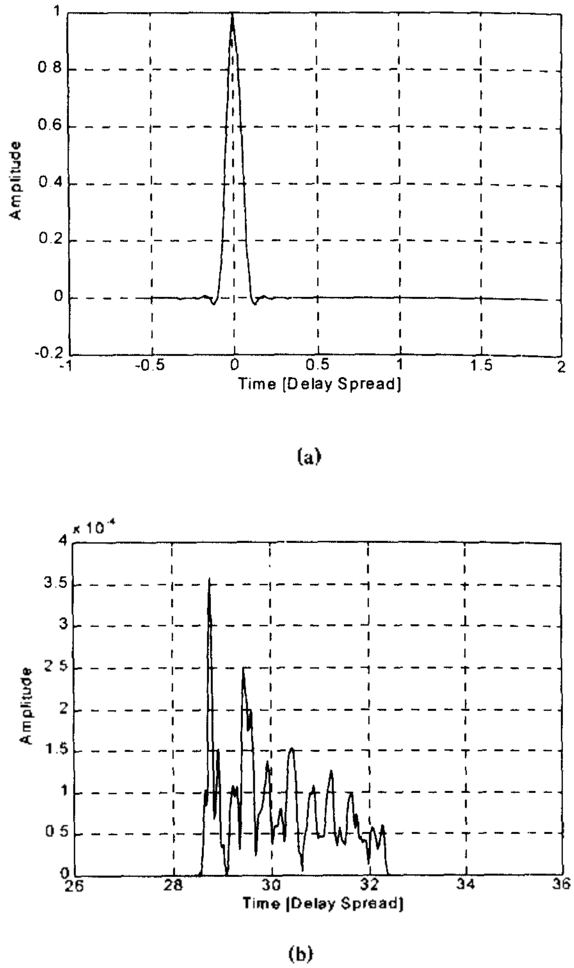


Figure 5. Received instantaneous signal, antenna position 100λ; (a) transmit chip waveform, (b) magnitude.

ding waves. The Rician channel is suitable to model PCS and Satellite communication environment. The statistics of the received signal via this channel are described by

$$p(r)dr = (r/\sigma^2)e^{-(r^2+A^2)/2\sigma^2}\, I_0(rA/\sigma^2)dr.$$

Here, I_o is zero-order modified-Bessel function and r, A is amplitude of received signal and power of direct signal, respectively. σ^2 is mean power of in-phase and quadrature-phase component of multipath signal.

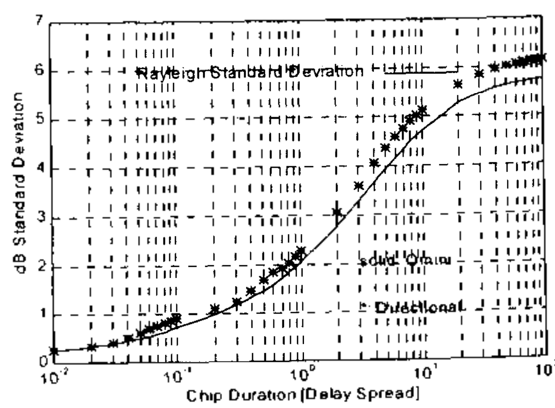
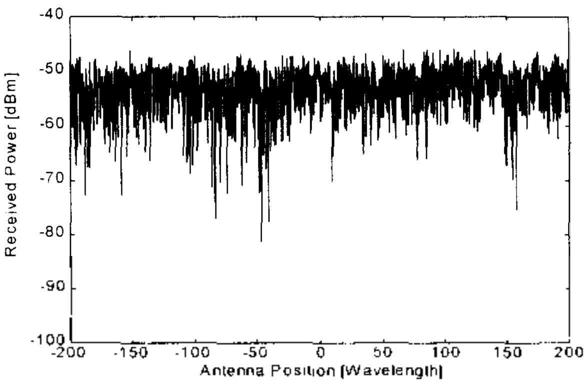


Figure 6. Variability of DS/SS signal strength with bandwidth of DS/SS signal.

2.3.1 Narrowband Signaling

Let the impulse response of direct path and multipath channel be $h_d(R, t)$ and $h_i(R, t)$, respectively. The impulse response of direct path channel is described by $h_d(R, t) = a\alpha(R)\delta(t - R/C)$, where a determines the strength via direct path. Therefore, the received signal from Rician channel is given by



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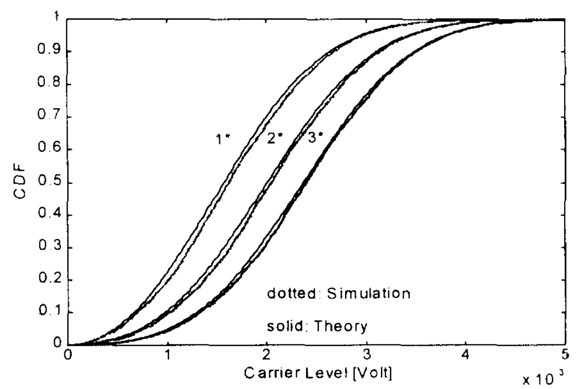

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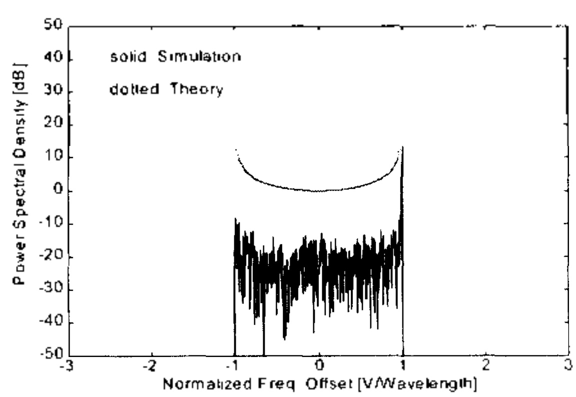

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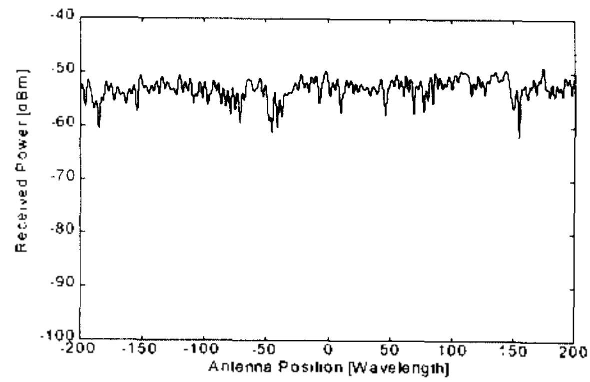
Figure 7. Simulated Rician fading signal ($A = \sqrt{3}\sigma$), unmodulated carrier, omnidirectional antenna; (a) received signal envelope, (b) CDF statistics, (b) diffuse Doppler spectrum.



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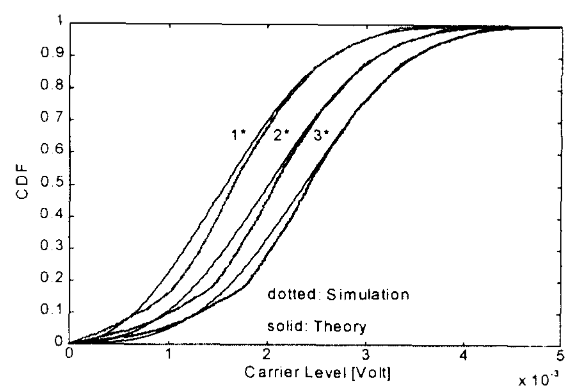

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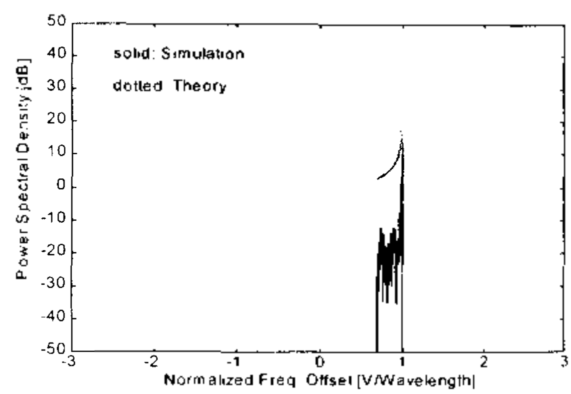

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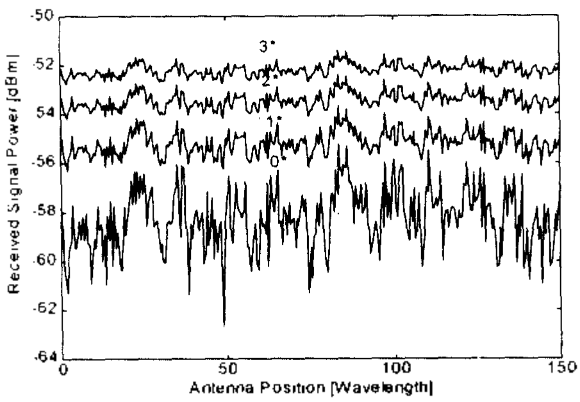
Figure 8. Simulated Rician fading signal ($A = \sqrt{3}\sigma$), unmodulated carrier, directional antenna; (a) received signal envelope, (b) CDF statistics, (c) diffuse Doppler spectrum.



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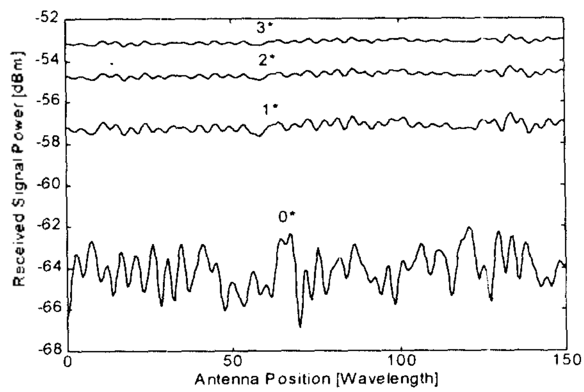

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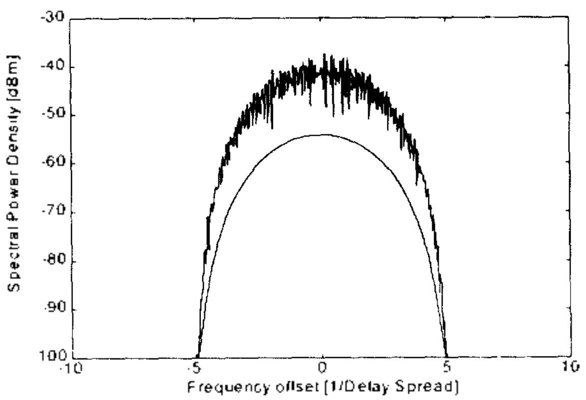

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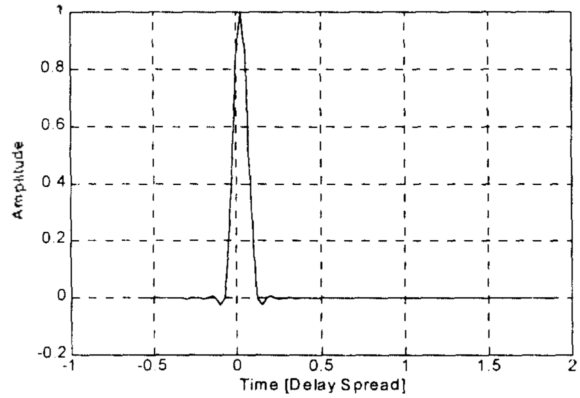
Figure 9. Simulated Rician fading signal at mobile location 100λ, DS-SS : (a) received signal envelope from omnidirectional antenna, (b) directional antenna, (c) spectral power density.



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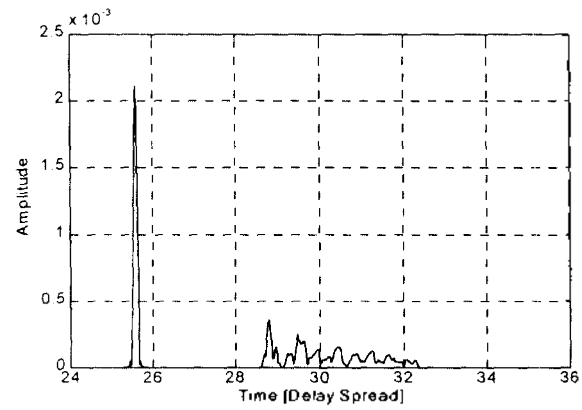

(b)

Figure 10. Received instantaneous signal, antenna position 100λ : (a) transmit chip waveform, (b) magnitude.

$$r(R,t) = r_d(R,t) + r_i(R,t) = s(R,t) * [h_d(R,t) + h_i(R,t)]$$

$$= e^{j2\pi f t} * [a_d(R)\delta(t - R/C) + \sum_n \alpha_n(R)\delta(t - \tau_n(t))]$$

$$= [\frac{a e^{-j2\pi f_c R/C}}{4\pi R/\lambda} + \sum_n \alpha_n(R) e^{-j2\pi f_c \tau_n(t)}] e^{j2\pi f_c t}.$$

The envelope of received signal is $r(R) = A e^{-j2\pi f_c R/C} + \sum_n \alpha_n(R) e^{-j2\pi f_c \tau_n(t)}$, where $A = a/(4\pi R/\lambda)$. For the simulations, the power of received signal via direct path was changed by integer multiple of power of multipath signal (-57.97dB). Figure 7 and 8 show the received signal envelope, CDF statistics for $A = \sigma$, $\sqrt{2}\sigma$, $\sqrt{3}\sigma$, and Doppler spectrum for $A = \sqrt{3}\sigma$ in omnidirectional and directional antenna reception, respectively. As expected, the variation of received signal decreases as increasing power of direct signal. The discrepancy for directional antenna case is due to insufficient number of scatterers as in Rayleigh fading case.

The Doppler spectrum showing a strong power at $f_c + f_m$ owes to a direct wave propagation toward mobile movement.

2.3.2 Wideband Signaling

The spectrum of a direct signal is given by $R_d(R, \omega) = \sum_k H_d(R, \omega_k) S(\omega_k)$, where transfer function of direct path is

$$H_d(R, \omega_k) = a\alpha(R) e^{-j2\pi R/\lambda_k} = \frac{a e^{-j2\pi R/\lambda_k}}{4\pi R/\lambda_k}.$$

The received signal via Rician channel is then

$$r(R, t) = F^{-1}\{R_d(R, \omega) + R_i(R, \omega)\}.$$

Figure 9 shows the received signal as a function of power of direct signal and the spectral power density of the received signal. The results indicate that anti-fading effect using wideband signal cannot be obtained as much as Rayleigh channel case and the spectrum of received signal contains almost the spectrum of transmit signal. Time waveform of received signal via Rician channel shown in Figure 10 indicates that detector can recover the signal easily.

Ⅲ. Conclusions

In this paper, existing narrowband model for the characterization of mobile channel model is extended for the wideband pulse with an arbitrary shape. To obtain the instantaneous received signal, the transfer function of the propagation channel weighted by the spectral shape of pulse is inversely Fourier transformed. Simulated results such as the received signal spectral density, CDF statistics of the fading signal, and Doppler spectrum of DS-SS signal via Rayleigh and Rician channel are shown to be machted well with both theoretical fading statistics and classical theory.

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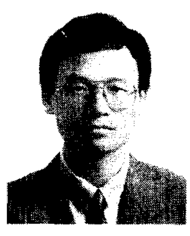
▲Chankil Lee

Chankil Lee received the B.S. degree in electronic engineering from Hanyang University in 1981, and the M.S. degree from the Seoul National University in 1983 and the Ph.D. degree from Georgia Institute of Technology, Atlanta, Georgia, in 1992. From 1983 to 1985, he was involved in development of TDX-1 ESS at ETRI. During 1986-1992, he worked on the radio signal processing and the diffraction problems of acoustic radiators. In 1992, he joined the Radio Technology Department at ETRI, where he worked on CDMA mobile radio systems. Since 1995, he has been an Assistant Professor at the Department of Electronic Engineering, Hanyang University, Ansan. His research interests include wave propagation and diffraction theory, multipath fading channel characterization, and performance analysis for various CDMA link design.

▲Youngsik Jeon

Youngsik Jeon studied electronic engineering at Hanyang University where he received the B.S. degree in 1996. He is currently working toward the M.S. degree at Hanyang University where he studies performance analysis for various Code Division Multiple Access (CDMA) systems.

▲Deuk-Su Lyu



Deuk-Su Lyu he received the B.S. degree from Hanyang University, and the M.S. degree in Electrical Engineering from Korea Advanced Institute of Science and Technology, Seoul, in 1983 and 1985, respectively.

Since then he has joined ETRI and had been engaged in development of the TDX-1 and TDX-10 digital switching systems until 1992. He has experience of developing voice and signaling service subsystems in the switching systems. Since then he had worked in the area of selecting and transcoding system development of Code Division Multiple Access (CDMA) digital cellular communication based on IS-95 until 1994. After that he had been involved in the test bed development for wideband CDMA Personal Communication System (PCS), having experience of developing the baseband modem.

He participates in development of the baseband modem for Wireless Local Loop (WLL) and International Mobile Telecommunication (IMT)-2000, or Future Public Land Mobile Telecommunication Systems (FPLMTS).

He is a senior member of technical staff at Radio Communications Design Section.