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광대역 다중경로 실측채널에서W-CDMA 수신 신호의 확률 모델

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Probability Models of W-CDMA Signals in Realistic Wideband Multipath Channels

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ABSTRACT

This paper proposes new probability models for wideband code division multiple access (W-CDMA) signals. The performance of a W-CDMA system is evaluated by calculating the average bit error rate(BER) which is derived from the probability distribution of the W-CDMA receiver output. If a probability model of the receiver output is available, the performance evaluation becomes much simpler and it enables diverse analyses of the system for channel coding and other purposes.

In this paper, probability distributions of W-CDMA signals, more specifically those of the receiver output, are represented as Rayleigh and noncentral chi distribution, considering various bandwidths and channel environments. The adequacy of a probability model is verified by chi-square test of 1% significance level. The BER of the system obtained from the simulation results is compared to that obtained from the probability model to demonstrate the usefulness of the proposed models.

I. Introduction

The third generation mobile communication system is required to provide flexible and high-data-rate services such as multimedia and internet connections. Wideband code division multiple access (W-CDMA) system is one of international standards as a common air interface(CAI) for the next generation mobile radio system called IMT-2000[1].

Recently, there have been extensive research for the evaluation of W-CDMA systems to quantitatively measure the performance of the system[2-4]. The performance analysis of W-CDMA system is usually carried out by calculating the average error rate(BER) for a given signal-to-noise ratio which has been evaluated by a mathematical analysis, field trials or simulations[2-3],[5].

In a mathematical analysis, models of the channel and the receiver are formally established in mathematical equations from which the BER is computed. It requires complicated calculations and would take much time to yield any useful results. Moreover, when a target system is complex, representing the system behaviour in mathematical equations becomes very difficult.

In field trials, a test system is implemented and set up in a real channel environment. When signals arrive at the receiver, output signals of the receiver are compared to the original source data, from which the BER can be obtained.

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However, when different channel environment has to be considered, the whole test system should be newly set up, which becomes costly and time consuming. To avoid high cost of building the test system, simulation can be used in which building block of the test system is implemented as program units and the sample data are processed by the program units to obtain the desired output of the system for the calculation of the BER. But it also takes much time because of large sample data whose size ranges usually from 10^4 to 10^7.

Therefore, if a general probability model is available, the received signal can be easily obtained from the model and hence the performance evaluation of the system can be performed very fast. Also it can be employed in diverse analyses of the system for other purposes such as the channel coding and system level simulation[6].

In this paper, we focus on representing the probability distribution of the output signal of a W-CDMA receiver as a probability model of Rayleigh or noncentral chi distribution considering different bandwidths and various channel environments. To obtain the probability model, output signals of the W-CDMA receiver is generated by simulation in which each part of the system has been implemented as a program unit by the pre-established mathematical analysis[7-11] and the units are assembled into a whole system.

Also statistical characteristics of the signals at the receiver output are extracted, which are finally represented as Rayleigh or noncentral chi distribution.

For the simulation of W-CDMA systems, establishing the channel model comes first. The wideband channel model is shown in section Ⅱ, in which the wideband multipath channel is modeled as a linear filter whose amplitude coefficient is Rayleigh distributed. In section Ⅲ, asynchronous W-CDMA signals over wideband multipath channel is analyzed considering all multipath effects. In section Ⅳ, simulation environments are explained and in section Ⅴ, the modelling procedure of received signals are given with experimental results and conclusions follow in section Ⅵ.

Ⅱ. Wideband multipath channel

The wideband multipath channel is generally modeled as a tapped delay-line linear filter in Eq.(1)[7].

$$h(t) = \sum_{l=0}^{L-1} a_l \delta(t-\tau_l) e^{j\theta_l} \tag{1}$$

This channel model is described with a set of variables which are the path strength a_l,, the time delay τ_l and the phase shift θ_l . The path strength a_l can be represented generally as a exponentially decaying function. However, there could be several variants by how exactly the real environment is reflected. In this paper, the one recommended by the Joint Technical Committee (JTC) is chosen as a wideband multipath channel model, which has been used for the simulation of radio propagation in different areas for PCS and mobile users, and known as a more elaborate and comprehensive model than other channel models. The JTC channel model is a discrete Wide-Sense Stationary Uncorrelated Scattering (WSSUS) channel model, whose channel impulse response is represented by the sum of delayed replicas for the impulse signal weighted by independent zero-mean complex Gaussian time variant process, and represented as in Eq.(2)[9].

$$h(t) = \sum_{l=0}^{L-1} \sqrt{p_l}\, a_l \delta(t-t_l) e^{j\theta_l} \tag{2}$$

Here, p_l, a_l, τ_l, and θ_l are respectively the average power, the amplitude, the time delay, and the phase shift of the l-th multipath in tapped delay-line linear filter model. The p_l and τ_l are constants taken from the l-th component of the JTC delay-power profile.

To apply the JTC channel model to our work, we must define the probability distribution of a_l and θ_l to represent a target channel environment.

a_l is the Rayleigh distributed random variable obtained from the amplitude of independent zero-mean complex Gaussian time variant process and θ_l is the phase of the independent zero-mean complex Gaussian time variant process. The phase of the various paths are mutually independent random variables which are uniformly distributed over $(0,2\pi]$[9-10].

This kind of wideband multipath channel model can be used for the analysis of a mobile radio system whose bandwidth is less than or equal to that of a channel model. The time resolution of a multipath channel is limited by the channel bandwidth. A narrower bandwidth channel model has longer time resolution while a wider bandwidth channel model has a shorter time resolution. Since there are more resolvable paths in a wider bandwidth channel, these cannot be represented accurately on a narrower bandwidth channel model.

In this paper, CDMA systems with 1.25MHz, 2.5MHz, 5MHz, and 10MHz bandwidths are considered. Therefore, we assume the time resolution is 100ns which correspond to a channel of 10MHz bandwidth. Note that 10MHz bandwidth is typical in many measurements for the analysis of CDMA system.

Ⅲ. Analysis of W-CDMA over a wideband multipath channel

In W-CDMA systems, the received signal is composed of several direct sequence(DS) waveforms which are transferred from end-users and are asynchronous to one another in uplink. We employ the coherent Binary Phase Shift Keying (BPSK) which is one of the basic modulation schemes in digital communication systems. In the following analysis, we assume that power control, code synchronization, carrier synchronization, and bit synchronization are performed ideally. Also, low data- rate services are conidered.

The signal transmitted by k-th user is represented as

$$s_k(t) = m_k(t)\,c_k(t)\,e^{(j\omega_0 t)}\ , \tag{3}$$

where $m_k(t)$ is a random binary sequence representing the data of the k-th user, $c_k(t)$ is the spreading sequence of the k-th user and it is assumed that the full period of a spreading sequence is equal to one symbol duration. Then the total received signal r(t) can be represented by Eq.(4).

$$r(t)= \sum_{k=0}^{K-1}\sum_{l=0}^{L-1}\sqrt{p_l}\,\alpha_{k,l}\, m_k(t-\tau_{k,l})c_k(t-\tau_{k,l})\, e^{[j\omega_0(t-\tau_{k,l})+\theta_{k,l}]} + n(t)\ , \tag{4}$$

where K is the total number of users, L is the total number of multipaths, and n(t) is the additive Gaussian noise.

In this equation, r(t) is composed of the following three parts.

1) multipath components from desired user. (*k=0* : wanted signal)

2) multipath components from undesired user. (*k=1,2,..,K-1*: interference signal)

3) additive noise. (usually Gaussian distributed unwanted noise)

The multipath components in the channel are indexed by the symbol l and $\tau_{k,l}$ and $\theta_{k,l}$ represent the delay time and the phase shift of the signal in l-th multipath component which comes from the *k*-th user.

The output of a standard correlation receiver at *t=T* is given by

$$\begin{aligned} Z(T) &= \int_0^T 2r(t)\,c_0(t)\,e^{j(w_0 t+\theta_0)}\,dt \\ &= \int_0^T 2\{s_0(t)+s_i(t)+n(t)\}\,c_0(t)\,e^{j(w_0 t+\theta_0)}\,dt \\ &= S'+I'+N'\ , \end{aligned} \tag{5}$$

where S', I' and N' are the desired user signal, the interference component, and the Gaussian noise of the correlator output respectively. To find out the statistical properties of $Z'(T)$, we need to analyze the statistics of each component S', I', and N' respectively. Consider the statistics of the wanted user signal

S' which can be written by Eq.(6) (for details, refer to [11]).

$$S' = |R| = \left| \sum_{l=0}^{L-1} \sqrt{p_l}\, a_{0,l} \exp(j\,\phi_{0,l}) R_c(\tau_{0,l}) \right| \tag{6}$$

S' represents the envelope of output signal which is summed with several multipath components considered autocorrelation function within one chip duration.

Also, the despread multiple access interference(MAI) I' is well-known to follow the Gaussian distribution and the noise N' is assumed to follow the additive Gaussian distribution[12-13].

We employ a RAKE receiver with maximal ratio combining(MRC) diversity as a W-CDMA receiver, which uses resolvable multipath components in order to increase the received signal-to-noise ratio(SNR). With M-th order MRC diversity, the equation for the output signal of the RAKE receiver can be written as follows.

$$S = \sum_{i=0}^{M} G_i S_i', \tag{7}$$

$$I = \sum_{i=0}^{M} G_i I_i', \tag{8}$$

$$N = \sum_{i=0}^{M} G_i N_i', \tag{9}$$

where G_i represents the gain and S_i', I_i' and N_i' are respectively the S', I' and N' of the i-th branch in the RAKE receiver. The gain is the ratio of the signal voltage to the summation of noise power and interference power, which is given by Eq.(10)[13].

$$G_i = \frac{Z_i}{var(I') + var(N')}\ . \tag{10}$$

Then the conditional probability of error for a given S can be written as

$$P(error|S) = Q\left(\frac{E[Z(T)|S]}{\sqrt{Var[Z(T)|S]}}\right)$$

$$= Q\left(\frac{S}{\sqrt{Var[I] + Var[N]}}\right) \tag{11}$$

where $Z(T)$ is $S+I+N$, and Q( ) is Q-function which is defined as $Q(x) = \oint_x^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy$.

The average error probability of the system is given by Eq.(12).

$$P_e = \int P(error|S)\, p(s)\, ds \tag{12}$$

where $p(s)$ is the probability density function(pdf) of the random variable S.

$p(s)$ can be obtained from S which is generated by simulation with appropriate random number generator as shown in the next section and we explains how the generated $p(s)$ is represented by a probability model in section Ⅴ.

Ⅳ. Simulation environments

We consider two different channel environments, i.e. the outdoor urban high-rise and the outdoor residential area, and four different bandwidths which are narrowband CDMA 1.25MHz, wideband CDMA 2.5MHz, 5MHz, and 10MHz.

The environments are specified in the JTC channel model and are further divided into the low-antenna case and the high-antenna case, resulting in four different classes of target environments. The channel parameters are given in Table 1 and Table 2[9] which are taken from JTC recommandation.

The purpose of this simulation is to find the pdf p(s) of CDMA signal S over each channel environment and S is generated based on Eq.(7). pdfs obtained from the simulation results for

Table 1. JTC channel model parameter for outdoor urban high-rise low antenna and high-antenna.

Tap	Urban high-rise low-antenna	
	Relative Delay(nsec)	Average Power(dB)
1	0	0
2	200	-0.9
3	800	-4.9
4	1200	-8.4
5	2300	-7.8
6	3700	-23.9

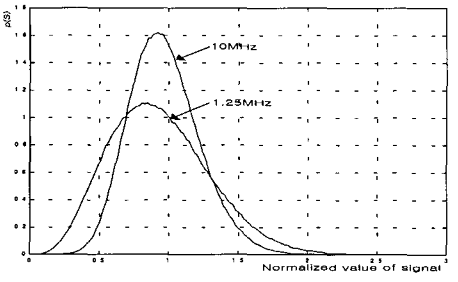
Tap	Urban high-rise high-antenna	
	Relative Delay(nsec)	Average Power(dB)
1	0	0
2	200	-4.9
3	500	-3.8
4	700	-1.8
5	2100	-21.7
6	2700	-11.5

bandwidths of 1.25MHz and 10MHz are shown in Fig. 1 and Fig. 2. The results for 2.5MHz and 5MHz are omitted. Also, these pdfs are normalized to have the unit power.

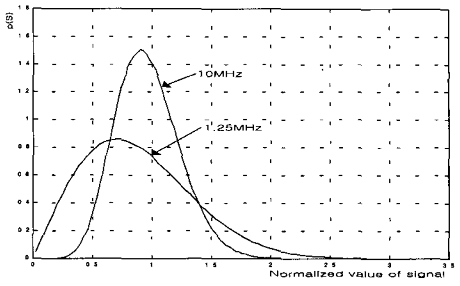
Table 2. JTC channel model parameter for outdoor residential low antenna and high-antenna.

Tap	Outdoor residential low-antenna	
	Relative Delay(nsec)	Average Power(dB)
1	0	0
2	200	-1.4
3	500	-2.4
4	700	-4.8
5	1100	-1.0
6	2400	-16.3

Tap	Outdoor residential high-antenna	
	Relative Delay(nsec)	Average Power(dB)
1	0	-3.8
2	100	0
3	500	-6.6
4	800	-1.2
5	1300	-18.4
6	1700	-23.7

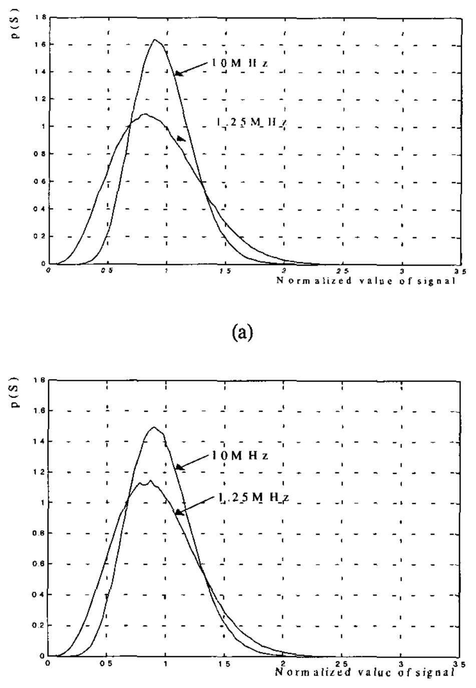


(a)



(b)

Fig.1 Pdfs of signal(S) for different bandwidth in outdoor urban high-rise (a)low-antenna and (b) high-antenna.



(a)

(b)

Fig. 2. Pdfs of signal(S) for different bandwidth in outdoor residential (a) low-antenna and (b) high-antenna.

V. Probability model

Until now, the typical shape of probability density function of the received signals are obtained with different bandwidths. From the statistics, we can predict the probability model of the received signal, for which we take two different types of distribution; the Rayleigh distribution and the offset noncentral chi distribution with three degrees of freedom.

The Rayleigh distribution is suitable for narrowband CDMA in an urban high-rise high-antenna case while the offset noncentral chi distribution is appropriate for wideband CDMA. The noncentral chi distribution function with three degrees of freedom is shown in Eq.(13)[10][14].

$$f_R(r)=\frac{r^{3/2}}{\sigma^2 s^{1/2}}e^{-(r^2+s^2)/2\sigma^2}I_{\frac{1}{2}}\left(\frac{rs}{\sigma^2}\right),\ r\geq 0 \qquad (13)$$

In Eq.(13), r is random variable of the probability model, which means the received signal. $I_{1/2}$ is the 1/2th-order modified Bessel function of the first kind and s^2 is noncentrality parameter. s^2 is defined as $s^2=m_1^2+m_2^2+m_3^2$, where m_1, m_2 and m_3 are the means of the three independent Gaussian random variables.

To verify the estimated probability model, we use a chi-square test which is defined as the weighted difference between the observed frequency of outcomes k_i and the expected frequency m_i in the i-th interval as shown in Eq.(14)[14]

$$q=\sum_{i=1}^{N}\frac{(k_i-m_i)^2}{m_i} \qquad (14)$$

Table 3 and Table 4 show the probability models for each environment and bandwidth, all of which satisfy the chi-square test with 1% significance level. From the Table 3-4, the distribution type in almost of all environments and bandwidths is offset noncentral chi distribution. In the case of 1.25MHz, received signal in outdoor high-rise high-antenna is Rayleigh distributed, while the others are not accorded with Rayleigh distributed because more outputs of Rake branches are summed in co-phase.

The BER derived from the probability model and that obtained from the simulation are shown in Fig.3 and Fig.4 for comparison. Note that the comparison shows that there is little difference between them. These figures demonstrate the usefulness of the proposed models by showing that the probability models can also give accurate estimation of BER of the system without original data.

Ⅵ. Conclusions

In this paper, we have proposed probability models for W-CDMA signals over wideband multipath channels. Based on the JTC model for the outdoor urban area and the residential area, the probability distribution of received W-CDMA signals with four different bandwidths is modeled as Rayleigh or offset noncentral chi distribution with three degrees of freedom. The adequacy of a probability model has been verified by chi-square test of 1% significance level. The BER obtained from the simulation results was compared to that obtained from the probability model to demonstrate the usefulness of the proposed models. For future study, probability model of high data-rate W-CDMA signals will be considered.

Table 3. Probability model for signal statistics in urban high-rise low-antenna and high-antenna.

Outdoor urban high-rise, low-antenna						
B.W	Distribution Type	Off -set	s^2	Mean	Var.	q
1.25 MHz	Offset noncentral Chi distribution (3 degrees Of freedom)	0.05	2.0	0.94	0.12	120.4
2.5 MHz		0.15	3.0	0.95	0.09	125.2
5MHz		0.26	3.1	0.96	0.07	128.2
10MHz		0.28	3.6	0.97	0.06	131.0

Outdoor urban high-rise, high-antenna						
B.W	Distribution Type	Off -set	s^2	Mean	Var.	q
1.25 MHz	Rayleigh	·	·	0.89	0.22	126.0
2.5 MHz	Offset noncentral Chi distribution (3 degrees Of freedom)	0.05	0.80	0.93	0.13	124.1
5MHz		0.24	3.02	0.96	0.07	131.5
10MHz		0.24	3.16	0.96	0.07	133.4

Table 4. Probability model for signal statistics in residential low-antenna and high-antenna.

Outdoor residential, low-antenna						
B.W	Distribution Type	Off-set	S^2	Mean	Var.	q
1.25 MHz	Offset noncentral Chi distribution (3 degrees Of freedom)	0.06	1.1	0.93	0.13	128.7
2.5 MHz		0.15	0.5	0.94	0.11	127.2
5MHz		0.26	3.7	0.97	0.06	125.4
10MHz		0.28	3.6	0.97	0.06	126.6

Outdoor residential, high-antenna						
B.W	Distribution Type	Off-set	S2	Mean	Var.	q
1.25 MHz	Offset noncentral Chi distribution (3 degrees Of freedom)	0.05	2.0	0.94	0.12	127.5
2.5 MHz		0.15	2.3	0.95	0.10	129.3
5MHz		0.14	1.0	0.94	0.11	131.1
10MHz		0.22	3.6	0.96	0.07	134.3

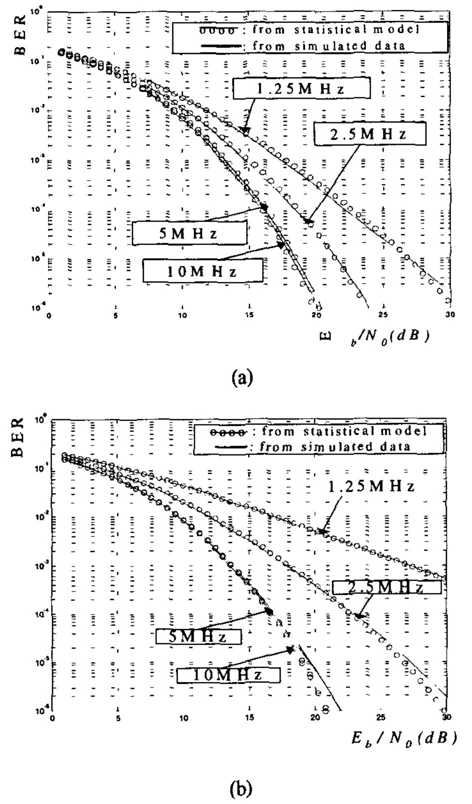


Fig. 3. BER comparison between the statistical model and the simulated data in urban high-rise (a) low-antenna (b) high-antenna.

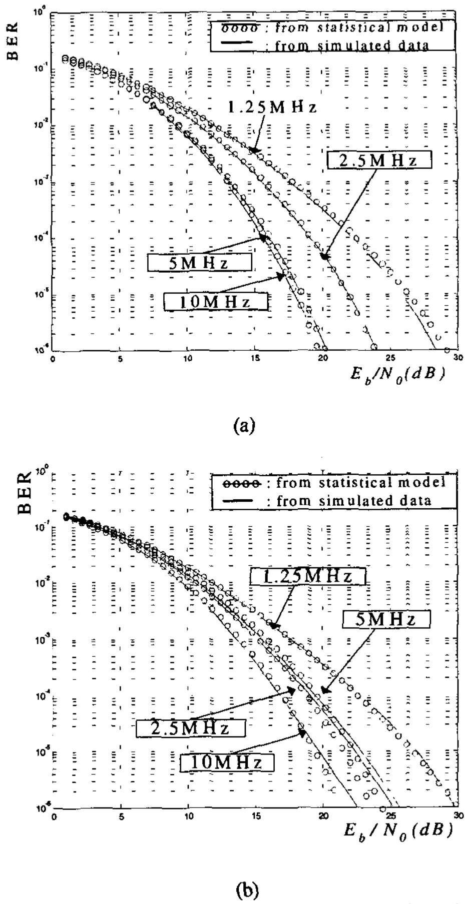


Fig. 4. BER comparison between the statistical model and the simulated data in outdoor residential (a) low-antenna (b) high-antenna.

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