CDMA 이동통신시스템에서 멀티미디어 트래픽의 요구 신호 전력 특성

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Characteristics of the Required Signal Power for Multimedia Traffic in CDMA Systems

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ABSTRACT

The reverse link signal power required for multimedia traffic in multipath faded single-code (SC-) and multi-code CDMA (MC-CDMA) systems is investigated. The effect of orthogonality loss among multiple spreading code channels is herein characterized by the orthogonality factor. The required signal power in both the CDMA systems is then analyzed in terms of the relative required signal power ratio of data to voice traffic. The effect of varying system parameters including spreading bandwidth, the orthogonality factor, and the number of spreading codes are examined. Analytical results show that MC-CDMA users transmitting only a single traffic type require significantly more power than SC-CDMA users with only a single traffic type. On the other hand, MC-CDMA users transmitting multimedia traffic require power levels approximately identical to SC-CDMA users with multimedia traffic. The results can be used in the design of radio resource management (e.g., power allocation) scheme for wireless multimedia services.

Ⅰ. Introduction

Code division multiple access (CDMA) techniques have many attractive features for application to second and third generation mobile communication systems. Two approaches for application of CDMA have been studied. These are a single-code CDMA (SC-CDMA) scheme that transmits user information on a single code channel [1], and a multi-code CDMA (MC-CDMA) technique that transmits user information with a high bit rate through multiple parallel code channels [2]. The MC-CDMA system offers the advantages of uniform and high processing gains for multiple traffic types, and can provide efficient implementation based on inherent parallelism, reduced inter-symbol interference (ISI) with a lower transmission rate, and flexible transmission of user information with a high data-rate based radio link availability [3].

Reverse link user signal power is an important factor for determination of system performance because it is directly proportional to the user transmission power that restricts the availability of a limited power source of portable terminals. The user signal power in both CDMA systems is identical in the ideal case where spreading code channels are orthogonal [4]. However, in real environments, orthogonality is lost due to multipath propagation and different code channels in MC-CDMA systems interfere with each other [5], [6]. This mutual interference affects the user signal power of the systems. As a result, MC-CDMA users with only a single traffic type

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논문번호 : 020157-0412, 접수일자 : 2002년 4월 12일

require significantly more power than SC-CDMA users transmitting only a single traffic type [7], [8].

Different signal power levels for different traffic types are required to guarantee acceptable link qualities (e.g., bit energy-to-interference density ratio). The required signal power in both CDMA systems is also different. In this paper, the characteristics of the signal power in multipath fading environments are investigated.

The reverse link characteristics of CDMA systems in multipath fading environments are discussed in Section II. The required signal power for multimedia traffic under various system parameters, including spreading bandwidth, the number of spreading codes, and the effect of orthogonality loss is evaluated in Section III. Numerical results are discussed in Section IV, and conculsions are presented in Section V.

Ⅱ. System Description

1. Reverse Link Characteristics

The required signal power dominantly depends on the mean transmission rate of user information, and thus, we are concerned with only the mean rate of the information in this study. Hereafter, for the simplification of the discussion, the terminology rate means mean rate.

In the MC-CDMA system considered, user information with a bit rate of R is transmitted after spreading with m parallel orthogonal code channels [2]. Thus, $R = mR1$, where $R1$ is the basic rate. When spreading codes are used in the ideal cases where the orthogonality among the code channels is maintained, mutual interference among the users code channels can be completely eliminated. However, mutual interference exists in real environments since orthogonality is lost due to multipath fading [5]. If perfect power control is assumed, then the bit energy-to-interference density ratio Eb/Nt received at a base station is maintained at a constant value. If Kmc users with a bit rate of R are conversing in a multiple cell MC-CDMA system, then the $(Eb/Nt)c$ for each code channel received at base station can be expressed as

$$\left(\frac{E_b}{N_t}\right)_c = \frac{P_1/R_1}{\{N_oW + I_{in} + I_o\}/W} = \frac{P_1/R_1}{\{N_oW + m[(K_{mc}-1)+(1-\delta)]P_1 + I_o\}/W}, \tag{1}$$

where m is the number of spreading codes assigned to a user, $P1$ is the received signal power for each code channel, No is the thermal noise density, W is the spreading bandwidth, Iin is the inner cell interference, Io is the outer cell interference, and δ is the orthogonality factor. δ represe nts the extent of orthogonality loss, i.e., the normalized mutual interference affecting the same multi-code user. For example, δ = 1 corresponds to the perfect orthogonality such that a code channel does not interfere with the other channels assigned to the same multi-code user. When δ = 0.4, a mutual interference of 60 % remains for the same multi-code user. In addition, δ = $1/m$ represents the complete non-orthogonality such that orthogonality among the number of spreading codes of m is completely lost, and thus, the fraction of $(m-1)/m$ affects mutual interference for the same multi-code user. However, δ = 0 indicates that a base station receiver can not detect any desired user signal in all the multi-code channels because mutual interference for the same multi-code user is significantly increased. The orthogonality factor is characterized by simulation methodology to be discussed below.

In SC-CDMA systems, user information is transmitted with a single spreading code channel. Single-code user signals are always asynchronous in the reverse link, and thus, the signals do not have orthogonality in multipath fading environments. If Ksc users with a bit rate of R are allocated in a multiple cell SC-CDMA system, the Eb/Nt required for a user is obtained by substituting $m=1$, $\delta=1/m$, $Kmc = Ksc$, $R_1=R$, and $P1 = P$ into Eq. (1), where P is the received signal power for a user. The signal power in each system is proportional to user transmitting power, and is required to maintain an acceptable link quality. Hereafter, the subscripts *sc* and *mc* will be used to denote the SC-CDMA and MC-CDMA system, respectively.

2. Orthogonaity loss in multipath fading channels

We characterize the degree of the orthogonality loss due to multipath fading (the orthogonality factor). In the reverse link of an MC-CDMA system, the user signal power received at a base station increases as the received interference increases. As a result, the *Eb/Nt* required for a multi-code user also increases to maintain a given link quality, measured as the bit error rate (BER). The required bit energy-to-interference density ratio in a nonfading channel, such as an additive white Gaussian noise (AWGN) channel, is lower than the required *Eb/Nt* in a multipath fading channel since the mutual interference due to orthogonality loss increases the received interference in the multipath fading channel. Therefore, the orthogonality factor of multi-code channels can be derived by comparing the effect of mutual interference among the multiple code channels assigned to a user on the required *Eb/Nt* in both AWGN and multipath fading channels. Thus, the orthogonality factor can be defined as

$$\delta \equiv \left(\frac{E_b}{N_o}\right)\left(\frac{E_b}{N_t}\right)^{-1}, \tag{2}$$

where *Eb/No* and *Eb/Nt* are the bit energy-to-interference density ratios in AWGN and multipath fading channels, respectively. The definition of Eq. (2) is adopted from [6], in which the values of *No* and *Nt* were considered as inter-cell interference approximated with Gaussian noise and intracell interference, respectively, in the forward link of an SC-CDMA system.

Fig. 1 shows the simulation model for derivation of the orthogonality factor in a single cell MC-CDMA system. First, user information is modulated with QPSK, spread with orthogonal Walsh codes, and randomized with a pseudo-random long sequence. We investigate the orthogonality factor using simulation for an AWGN channel and multipath fading channels with two different delay power profiles. The simulations are performed for the system with only a single multi-code user. Thus, there is no other-user interference. Only mutual interference exists among multiple code channels (inter-code channel interference).

The degree of the orthogonality loss depends on multipath delay power profiles of the propagation channel. Uniform and exponential distributions of the delay power profiles are considered. The uniform profile has *Lp* resolved paths with an equal average power. The exponential profile is a more realistic profile model where the average power decays exponentially as the path delay increases. The average of the squared path gains $E[|\xi_l|^2]$ of the l-th path is given by [5]

$$E[|\xi_l|^2] = \begin{cases} 1/L_p \quad \text{for} \quad 0 \le l \le L_p - 1, \ \textit{uniform} \\ [1-\exp(-\varepsilon)]\exp(-\varepsilon\, l) \ \text{for} \ 0 \le l, \ \text{exponential} \end{cases} \tag{3}$$

where ε is the decay factor. In the exponential power profile, hereinafter, *(Lp)90%* will be used to represent the number of resolved paths whose total power equals 90% of the total average power.

In the simulations, the parameters m = 6, *R1 = 64 kbps*, ε = 2.3/(*Lp*)90%, and *Lp* = 4, and 4 fingers at the Rake receiver are used. We generate a set of complex Gaussian path gains ξ_l's according to Eq. (3). This is repeated to

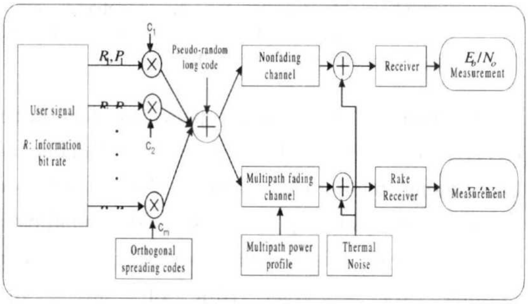

Fig. 1 Block diagram of simulation model in a single cell MC-CDMA system.

obtain the average BER and the required *Eb/Nt* under AWGN and multipath fading channels (*Eb/No* in AWGN channel).

For a target BER of 10^{-3}, $E_b/N_o \approx 7dB$, $(E_b/N_t)unif \approx 9dB$, and $(E_b/N_t)\exp \approx 10.2dB$ are given for the AWGN channel and multipath fading channels with uniform and exponential delay power profiles, respectively. Hence, from Eq. (2) we can obtain the orthogonality factor under the simulation conditions as 0.63 and 0.47 for uniform and exponential distributions, respectively. This indicates that the mutual interference among spreading code channels under a uniformly distributed multipath delay power profile can be more suppressed than for an exponentially distributed multipath delay power profile.

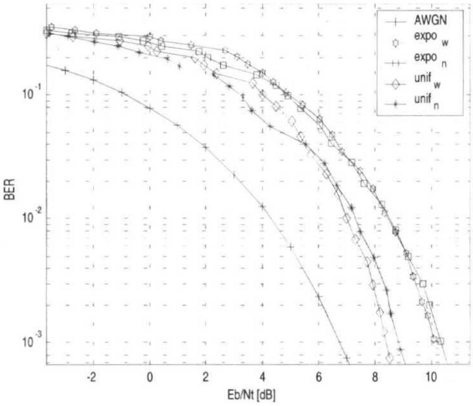

Fig. 2 Average BER versus required *Eb/Nt* for different multipath power profiles and the number of resolved paths (*unif*: uniform profile, *expo*: exponential profile, *n*: narrowband, and *w*: wideband): (narrowband case: processing gain = 60, *R1* = 64 *kbps*, *m* = 6, *Lp* = 4, the number of fingers = 4, wideband case: processing gain = 120, *R1* = 64 *kbps*, *m* = 6, *Lp* = 8, the number of fingers = 8).

The number of resolved paths at the Rake receiver also affects the degree of orthogonality loss among multi-code channels. As the number of resolved path *Lp* increases, the multipath combining gain slightly increases (Fig. 2). For example, for a target BER of 10^{-3}, the combining gains of about 0.4 *dB* and 0.2 *dB* are achieved for uniform and exponential profiles, respectively, by a two-fold increase in the number of resolved paths. Hence, the orthogonality factors are 0.69 and 0.5 for the uniform and exponential profiles, respectively. With a two-fold increase in the number of resolved paths, the orthogonality factor increases by approximately 6%. The achieved gains are not great because mutual interference among multi-code channels degrades the *Eb/Nt* performance.

The degree of orthogonality loss varies with given fading parameter values. As a special case, when user information with very high bit rates (with a larger *m*) is transmitted on a severe multipath channel, the required *Eb/Nt* for multi-code users may be significantly increased due to an increase in mutual interference. As a result, a base station receiver can not detect any desired user signals from *m* spreading code channels in terms of an acceptable signal quality. Thus, the communication link may be disconnected (That is, *the link capacity of the system approaches zero* (See Appendix A)). In this case, the orthogonality factor approaches zero. Therefore, we can specify the orthogonality factor as the value $(1/m) \le \delta \le 1$ (For single-code systems with $m=1$, mutual interference is absent).

Ⅲ. Required Signal Power for Multimedia Traffic

Suppose that an MC-CDMA system supports *M* types of traffic with each information bit rate $R_j (1 \le j \le M)$, which is an integer multiple of a basic rate R_1. In this system all signals of each traffic type are transmitted with the rate of R_1. Hence, when a higher rate information is transmitted, the information bit rate of *j*-th type of traffic is given by $R_j = mR_1$ where $m (1 \le m \le M)$ is the number of spreading codes for transmitting *j*-th type of traffic. Then the $(E_b/N_t)_j^c$ received at each code channel of the *j*-th type of traffic can be expressed as

$$(E_b/N_t)_j^c = \frac{P_j^c/R_1}{I_t/W} = \frac{P_j^c G_1}{P_t - m[1-(1-\delta)]P_j^c}, \quad (4)$$

where P_j^c is the signal power of each code channel of the j-th type of traffic received at a base station, δ is the orthogonality factor among multi-code channels, I_t is the total received noise plus interference power, W is the spreading bandwidth, P_t is the total received power including the desired signal power, and G_1 is the processing gain of the first type of traffic with 1-rate. As shown in Eq. (4), when $\delta=1$, the desired signal power subtracted from the denominator is given by mP_j^c whereas in the case of $\delta=1/m$, the desired signal power subtracted from the denominator is P_j^c. From Eq. (4), P_j^c is represented as

$$P_j^c=\frac{P_t\,\gamma_j}{G_1+m\,\delta\,\gamma_j}, \tag{5}$$

where γ_j is the E_b/N_t required for maintaining a given acceptable link quality of *j-th* traffic type. Hence, the required signal power for a multi-code user with *j-th* traffic type is given by

$$P_j=\frac{mP_t\,\gamma_j}{G_1+m\,\delta\,\gamma_j}, \tag{6}$$

To simplify our discussion, we herein assume that CDMA systems support two traffic types: voice and data. Then, from Eq. (6) the relative signal power ratio of data to voice traffic in the MC-CDMA system $(P_d/P_v)_{mc}$ is obtained as

$$\left(\frac{P_d}{P_v}\right)\equiv\Gamma_{mc}=\frac{m(G_v+\gamma_v)}{G_v+m\,\delta\,\gamma_d}\cdot\frac{\gamma_d}{\gamma_v}, \tag{7}$$

where G_v is the processing gain of voice traffic. Substituting $m=1$, $\delta=1/m$, and $G_1=G_j$ into Eq. (6), the relative signal power ratio of data to voice traffic in the SC-CDMA system is given by [8]

$$\left(\frac{P_d}{P_v}\right)\equiv\Gamma_{sc}=\frac{G_v+\gamma_v}{G_v+\gamma_d}\cdot\frac{\gamma_d}{\gamma_v}, \tag{8}$$

where G_d is the processing gain of data traffic. From Eqs (7) and (8), the ratio Γ_{mc}/Γ_{sc} is expressed as

$$\frac{\Gamma_{mc}}{\Gamma_{sc}}=\frac{m(G_d+\gamma_d)}{G_v+m\delta\,\gamma_d}=\frac{G_v+m\,\gamma_d}{G_v+m\,\delta\,\gamma_d}. \tag{9}$$

From Eq. (9), we can see that Γ_{mc} is larger than Γ_{sc} except when mutual interference among multi-code channels is absent.

Ⅳ. Numerical Results

The signal power required for multimedia traffic is investigated and compared for MC-CDMA and SC-CDMA systems in multipath fading environments. The signal power is evaluated under various system parameters including spreading bandwidth, the orthogonality factor, information bit rates, and the number of spreading codes assigned to a user. In order to evaluate the signal power in the two CDMA systems, the system parameters as shown in Table 1 are considered. Figs. 3 through 5 illustrate the relative signal power ratio of data to voice traffic in the two CDMA systems.

Table 1. List of system parameters.

Information bit rate	voice, R_v	32 *kbps*
	data, R_d	128 *kbps*, 384 *kbps*
Required E_b/N_t, γ	voice, γ_v	7*dB*
	data, γ_d	8*dB*
Number of spreading codes assigned to a user, m		4, 12
Orthogonality factor		0.5

As the number of spreading codes increases the mutual interference among multi-code channels increases, consequently, the relative signal power ratios in both CDMA systems also increase. With a increase of spreading bandwidth, both of the relative signal power ratios, Γ_{mc} and Γ_{sc}, also increase (Fig. 3). That is, as the spreading bandwidth increases the signal power required for data traffic slightly increases in the CDMA systems. This is because Γ_{mc} is proportional to the number of spreading codes and processing gain of the basic-rate traffic (voice traffic). On the other hand, the effect of the increased processing gain for data traffic on interference suppression is less than that of voice traffic in the SC-CDMA system. For example, when $W=4.80MHz, m=4$, and $\delta=0.5$, $\Gamma_{mc}=4.80$ and $\Gamma_{sc}=4.45$, on the other hand, in the case of $W=19.20MHz$, $m=4$, and $\delta=0.5$, $\Gamma_{mc}=4.97$ and $\Gamma_{sc}=4.87$.

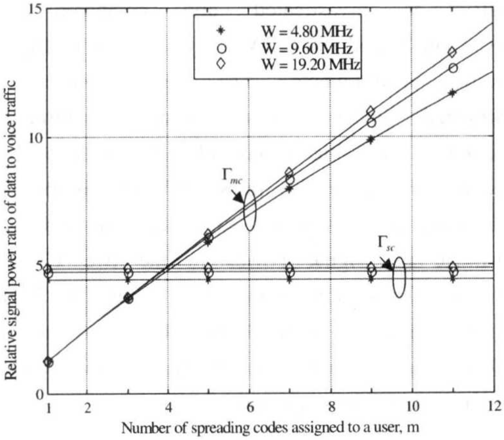

Fig. 3 Relative signal power ratio of data to voice traffic in CDMA systems according to the spreading code and bandwidth allocations ($R_v=32kbps, R_d=128kbps$, $m=4$, $\gamma_v=7dB$, $\gamma_d=8dB$).

Fig. 4 shows the effect of the required bit energy-to-interference density ratio for data traffic γ_d on the relative signal power ratios. As the required density ratio γ_d increases data traffic requires more power, as a result, the relative signal power ratio also increases.

Fig. 5 illustrates the effect of the orthogonality factor on the relative signal power ratios in the CDMA systems. As the orthogonality factor and spreading bandwidth increase, the relative signal power ratio Γ_{mc} decreases. For example, in the cases of $W=9.60MHz$, $\delta=0.5$ and $W=19.20MHz$, $\delta=0.5$, the relative power ratios are given by $\Gamma_{mc}=4.91$ and $\Gamma_{mc}=4.97$. However, when the orthogonality factor is less than 0.2, the effect of spreading bandwidth is reversed.

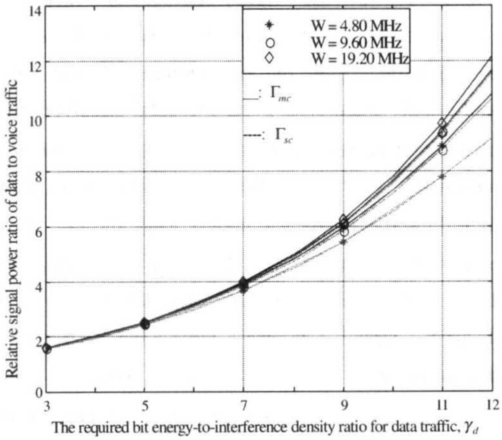

Fig. 4 Relative signal power ratio of data to voice traffic in CDMA systems according to spreading bandwidth and the required bit energy-to-interference density ratio for data traffic ($R_v=32kbps, R_d=128kbps$, $\delta=0.5$, $\gamma_v=7dB$).

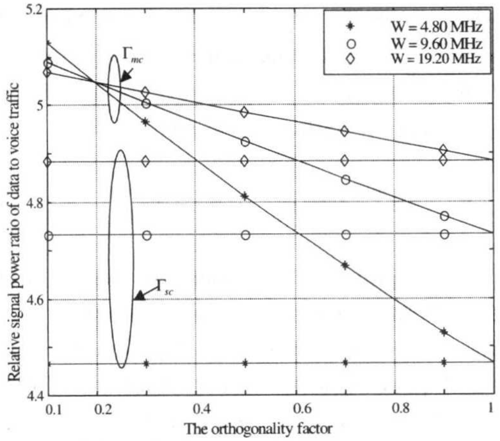

Fig. 5 Relative signal power ratio of data to voice traffic in CDMA systems according to the orthogonality factor and spreading bandwidth ($R_v=32kbps, R_d=128kbps$, $m=4$, $\gamma_v=7dB$, $\gamma_d=8dB$).

Table 2. Relative signal power ratio of data to voice traffic in the MC- and SC-CDMA systems.

(a) ($R_v=32kbps, R_d=128kbps$, $m=4$, $\gamma_v=7dB$, and $\gamma_d=8dB$)

	Bandwidth / Γ	$4.80MHz$	$9.60MHz$	$19.20MHz$
$\delta=0.5$	Γ_{mc}	4.80	4.91	4.97
	Γ_{sc}	4.45	4.72	4.87
	$\Gamma_{mc}\geq\Gamma_{sc}$	7.8 %	4.0 %	2 %

(b) ($R_v = 32kbps, R_d = 384kbps,\ m = 12,\ \gamma_v = 7dB,$ and $\gamma_d = 8dB$)

	Bandwidth Γ	4.80MHz	9.60MHz	19.20MHz
$\delta = 0.5$	Γ_{mc}	4.80	4.91	4.97
	Γ_{sc}	4.45	4.72	4.87
	$\Gamma_{mc} \geq \Gamma_{sc}$	7.8 %	4.0 %	2 %

Table 2 shows the difference between the relative signal power ratios in both CDMA systems $|\Gamma_{mc} - \Gamma_{sc}|$. As the number of spreading codes increases the difference also increases. However, this difference reduces as the spreading bandwidth increases. For example, a threefold increase in the number of spreading codes causes approximately a threefold increase in the difference of the relative signal power ratio. A threefold increase in the spreading bandwidth results in a threefold decrease in the difference. That is, when $W = 4.80MHz,\ m = 12,$ and $\delta = 0.5$, the relative signal power ratio of data to voice traffic in the MC-CDMA system is 20 percent higher than the ratio in the SC-CDMA system. However, in the case of $W = 19.20MHz,\ m = 12,$ and $\delta = 0.5$, the relative signal power ratio in the MC-CDMA system is only 6 percent higher.

When compared to the difference in the required signal power of the two CDMA systems supporting only a single type of traffic [7], [8], the difference of the relative signal power required for data and voice in both CDMA systems is significantly reduced. Furthermore, from Eq. (9) it is explicitly observed that the relative signal power required for multiple types of traffic in both the systems is identical when a code channel does not interfere with the other channels for the same multi-code user.

V. Conclusions

The reverse link of MC-CDMA and SC-CDMA systems in multipath fading environment is first characterized by the orthogonality factor among multiple spreading code channels. The reverse link signal power required for multimedia traffic is then analyzed in terms of the relative signal power ratio of data to voice traffic according to varying system parameters. Analytical results show that spreading bandwidth and the orthogonality factor significantly affect the required signal power in the systems

Furthermore, MC-CDMA users with multimedia traffic require a power level approximately identical to SC-CDMA users with multimedia traffic in multipath fading environments. On the other hand, MC-CDMA users with only a single type of traffic require significantly more power than SC-CDMA users transmitting only a single type of traffic [7], [8]. This result can be used in the design of power allocation scheme for wireless multimedia services.

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