LETTER

Effect of Spreading Bandwidth on DS-CDMA Reverse Link Capacity

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SUMMARY This paper addresses an important issue on the spreading bandwidth of direct sequence code division multiple access (DS-CDMA) cellular mobile radio systems: does wider spreading bandwidth provide larger capacity? And if so, to what extent? The capacity of the perfect power controlled reverse link is evaluated by computer simulation for 1.25 MHz and 5 MHz spreading bandwidths under various sets of propagation channel parameters (path loss decay factor, shadowing standard deviation, shadowing correlation, number of resolved propagation paths) and antenna diversity reception.
key words: *DS-CDMA, mobile radio, capacity, spreading bandwidth, reverse link*

1. Introduction

Wireless direct sequence code division multiple access (DS-CDMA) [1] is considered to be a promising mobile radio access technique. A DS-CDMA cellular system reuses the same carrier frequency at every cell, creating significant multi-access interference (MAI) from adjacent cells as well as the own cell. In general, the reverse link limits the transmission performance since all users are asynchronous. An important issue of DS-CDMA cellular mobile radio systems is on the spreading bandwidth: does widening the spreading bandwidth increase capacity? And if so, to what extent? There are a number of papers dealing with the capacity of power controlled DS-CDMA reverse link [4]–[11]. The most comprehensive study on the capacity of power controlled reverse links is presented in Ref. [11], for different bandwidths (1.25 and 10 MHz) under various channel parameters (path loss decay factor, shadowing standard deviation, and the number of resolvable paths) and base station antenna diversity reception. Widening spreading bandwidth has two effects. The sum of other-cell MAI has smaller variations due to the rule of large numbers since the system can accommodate more users per cell. Better transmission performance can be achieved due to enhanced RAKE combining since the number of resolvable propagation paths increases. These result in larger link capacity expressed in ksps/cell/MHz. It is shown in [11] that when 2-antenna diversity reception is used, the link capacity of a 10 MHz system is about 1.5–2 times larger than that of a 1.25 MHz system due to increased interference averaging and, furthermore, that the capacity is significantly affected by the path loss decay factor; larger decay factors yield larger capacity. In [11], a single data rate of 9.6 kbps is assumed along with shadowing standard deviation of 8 dB and 1 and 3 resolvable paths for 1.25 MHz and 10 MHz, respectively. However, multimedia type services may contain several data rate in 3rd generation mobile systems, and furthermore, the propagation channel parameters are environment dependent. In this paper, we consider the two different data rates, 8 and 64 ksymbol/s (ksps), and various propagation channel parameters, the number of resolvable paths L =1–8, shadowing standard deviation σ =6–10 dB, and shadowing correlation ρ =0.1–0.9. The reverse link capacities of 1.25 and 5 MHz are evaluated by computer simulation assuming perfect transmit power control and ideal coherent detection. Section 2 describes the computer simulation model and procedure. In this paper, to compare the link capacities of different bandwidths and different data rates, we define the capacity in terms of the throughput (ksps)/cell/MHz. Section 3 presents the simulation results and discusses the effects of various propagation parameters of channel.

2. Computer Simulation Procedure

2.1 System Parameters

We consider a cellular structure of 19 cells, the cell site having an omni directional antenna being located at the center of each cell. Assuming quaternary phase shift keying (QPSK) modulation, symbol transmission rates of $R_s = 8$ and 64 ksps are considered; the spreading factor G_{SF} is 128 and 16, respectively, for the 1.25 MHz (1.024 Mcps) system and four times for the 5 MHz (4.096 Mcps) system. We compare the link capacity (ksps/cell/MHz) assuming a total bandwidth of 5 MHz for two systems using the spreading bandwidths of 1.25 and 5 MHz.

2.2 Definition of Signal-to-Interference Plus Background Noise Ratio (SIR)

The multipath channel between a cell site and a mobile is assumed to be composed of L resolvable paths, each subjected to independent Rayleigh fading with power of $1/L$. The value of L depends on the spreading bandwidth. We assume that the RAKE combiner

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of cell site receiver is designed to collect all signal powers that propagated via L paths. The ith user that is communicating with the mth cell site is labeled the $i(m)$th user. Without transmit power control, the instantaneous signal power received at the 0th cell site of interest from the $i(0)$th user can be represented as $P_{R,i(0)} = w_{i(0),0} P_{T,i(0)}$, where

$$w_{j(m),n} = r_{j(m),n}^{-\alpha} \cdot 10^{-0.1\xi_{j(m),n}} \sum_{l=1}^{L} \left| h_{j(m),n}^{(l)} \right|^2$$
$$\text{with} \;\; j=i, \; m=n=0$$

with $r_{i(m),n}$ is the mobile-cell site distance, α is the decay factor, $\xi_{j(m),n}$ are the Gaussian variable representing log-normally distributed shadowing loss, and $h_{j(m),n}^{(l)}$ are the independent complex-valued Gaussian variables representing channel gain of the lth path between the $i(m)$th user and the nth cell site. Since the line of sight path between the cell site and the mobile is blocked mainly by obstacles, e.g. buildings, near the mobile station, the shadowing losses $\{\xi_{j(m),n}\}$ of the same user $j(m)$ for different n are partially correlated [3]. Now, we assume perfect transmit power control such that the received signal power of each user is held to unity. We need to consider the MAI from own cell users and that from other cell users to the $i(0)$th user signal, which are represented as $I_{own,i(0)}$ and $I_{other,i(m)}$, $m \neq 0$, respectively. Since the MAI power is reduced by a factor of G_{SF} due to the receiver filter which is matched to the spreading sequence of the $i(0)$th user, they are given by

$$wI_{own,i(0)} = G_{SF}^{-1} \sum_{\substack{all\, j(0) \\ \neq i(0)}} 1 \text{ and}$$

$$I_{other,i(0)} = G_{SF}^{-1} \sum_{\substack{all\, m \\ \neq 0}} \sum_{all\, j(m)} I_{j(m),0},$$

where $I_{j(m),0}$ is the MAI from the $j(m)$th user to the 0th cell site. Since the $j(m)$th user is power controlled by the mth cell site so that the received signal at the mth cell site is unity, the instantaneous transmit power of that user is given by $w_{j(m),m}^{-1}$. The transmit power of the $j(m)$th user is then, attenuated by a factor of $w_{j(m),0}$ when received at the 0th cell site. As a consequence, $I_{j(m),0}$ is expressed as $I_{j(m),0} = G_{SF}^{-1} \cdot w_{j(m),0}/w_{j(m),m}$. Finally, the received signal-to-interference plus background noise power ratio (SIR) $\lambda_{i(0)}$ is given by $\lambda_{i(0)} = (I_{own,i(0)} + I_{other,i(0)} + \gamma^{-1})^{-1}$, where γ is the signal-to-background noise power ratio (SNR). We assumed $\gamma = 25$ dB to simulate the interference limited condition.

2.3 Simulation Procedure

The link capacity is defined as the maximum number of users times the symbol rate (ksps)/cell/MHz on the condition that the required outage of the communications quality represented by the bit error rate (BER) is satisfied. Assuming ideal coherent detection, the BER of an uncoded channel is given by $P_{b,i(0)} = 0.5 erfc\sqrt{\lambda_{i(0)}}$. This is based on the assumption of very slow fading, in which the channel gains remain almost constant over the BER measurement interval. The outage is defined as $Q =$*average* of Prob$[P_{b,i(0)} < P_b]$, *on all* $i(0)$, where P_b is the required uncoded BER. In the simulation, it is assumed that $P_b = 0.01$ and $Q = 0.01$. Let N be the average number of users per cell. Starting from $N = 1$, the simulation proceeds as follows: (a) generate the random locations of $19N$ users over the entire area of 19 cells; (b) compute the distance dependent path losses $\{r_{j(m),n}\}$ and generate the shadowing losses $\{\xi_{j(m),n}\}$ between the nearest 3 cell sites and each user; (c) find the best cell site that provides the least sum of path loss and shadowing loss for each of $19N$ users, and determine the set of $\{j(m)\}$; (d) generate the channel gains $\left\{h_{j(m),n}^{(l)}\right\}$, compute the value of $\lambda_{i(0)}$ to obtain $\{P_{b,i(0)}\}$ for all $i(0)$'s; (e) repeat steps (d) 100 times; (f) repeat steps (a)–(e) 1000 times to compute the BER distribution from $\{P_{b,i(0)}\}$; (g) if the BER distribution at P_b is less than Q, let $N + 1 \rightarrow N$ and go back to step (a), otherwise, stop the simulation. The link capacity is given by $(N-1)R_s/5$ MHz. In the case of the 1.25 MHz system, each cell site has 4 different carriers, one of which is assigned to each user in such a way that the difference in the number of users among 4 carriers is equal to or less than 1.

3. Simulation Results

First, we evaluated the dependency of the capacity on the number of resolvable paths L assuming M-branch antenna diversity (the total number of paths is given by ML) and the results are plotted in Fig. 1. We assumed that the path loss decay factor $\alpha = 4$, the shadowing loss standard deviation $\sigma = 8$ dB, and shadowing correlation $\rho = 0.5$. Four conclusions can be drawn from this figure. First, the 5 MHz system can provide about 5% larger capacity than the 1.25 MHz system for the given value of L. This is because more users can be accommodated in the 5 MHz spreading bandwidth than in the 1.25 MHz spreading bandwidth, resulting in the increased effect of interference averaging. Note that wider spreading bandwidth provides better resolution of propagation channel and thus, $L_{5\,\text{MHz}} > L_{1.25\,\text{MHz}}$ in general. Hereinafter, we assume $L_{5\,\text{MHz}} = 4$ and $L_{1.25\,\text{MHz}} = 1$. Furthermore, we assume $M = 2$ and $R_s = 8$ ksps which yields the capacity of 163 ksps/cell/MHz for 5 MHz spreading, and 114 ksps/cell/MHz for 1.25 MHz spreading; about 43% greater capacity increase by widening the spreading bandwidth from 1.25 MHz to 5 MHz (this result is consistent with Ref. [11]). However, for $R_s = 64$ ksps, the

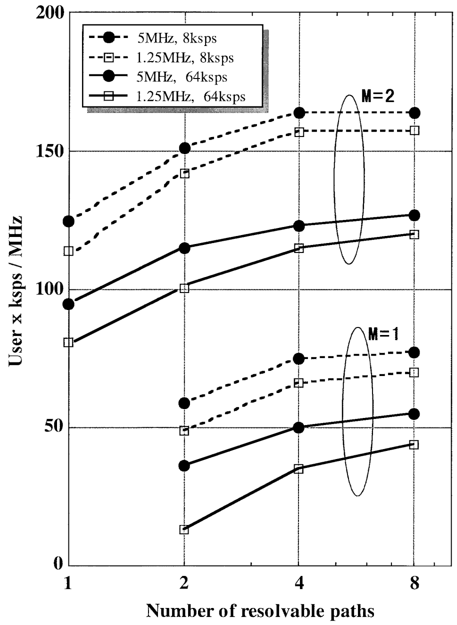

Fig. 1 Capacity dependency on L. $\alpha = 3.5$, $\sigma = 8$ dB, $\rho = 0.5$.

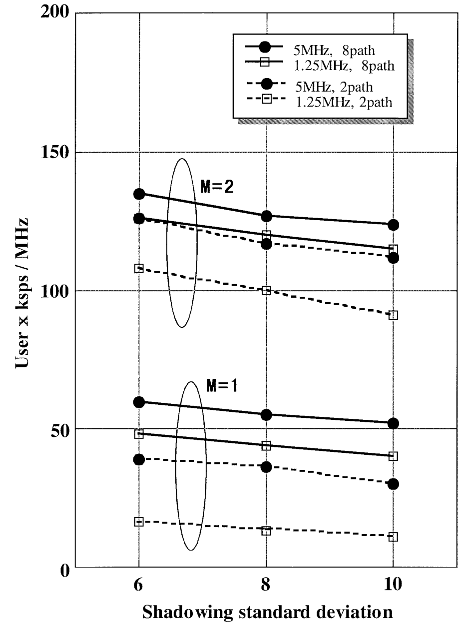

Fig. 2 Capacity dependency on σ. $\alpha = 3.5$, $\rho = 0.5$.

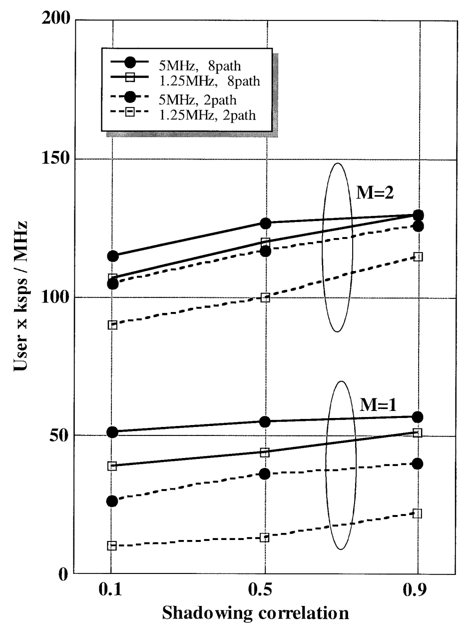

Fig. 3 Capacity dependency on ρ. $\alpha = 3.5$, $\sigma = 8$ dB.

capacity increase is about 56%. Second, the capacity is smaller with the transmission rate of 64 ksps than with 8 ksps since, for the former case, the number of users per cell is smaller and so, the interference averaging effect becomes smaller. Therefore, it is worth noting that we should be careful when estimating the link capacity for the case of mixed voice/data services. Third, as the value of L increases, the capacity increases for the given spreading bandwidth and transmission rate since the transmit power can be reduced due to the increased effect of RAKE combining, thus providing reduced MAI to other cells; however, the capacity almost saturates when $L > 4$. Fourth, 2-branch antenna diversity reception makes more than double the capacity for the given value of L. This is because diversity reception can reduce the mobile transmit power by half and, in addition to this, a doubling of the equivalent number of paths which further reduces the transmit power (this results in less than half the MAI from other cells compared with the $M = 1$ case). We also evaluated the dependency of the link capacity for $R_s = 64$ ksps on the shadowing standard deviation σ, shadowing correlation ρ, and path loss delay factor α. The simulation results are plotted in Figs. 2–4. Figure 2 plots the capacity as a function of σ ranging from 6 to 8 dB, values typical in mobile radio [12]. It can be seen from Fig. 2 that as the value of σ increases the capacity falls because of the increasing MAI from other cells, however, the reduction rate is rather slow for both for 1.25 and 5 MHz cases. If the shadowing correlation becomes strengthens, transmit power reduction in one cell reduces the MAI power to other cells and so, the capacity slightly increases as the value of ρ becomes larger. This is clearly seen in Fig. 3. Figure 4 plots the effect of α on the capacity. As the value of α becomes larger the capacity increases since the MAI power from the other cells decays faster. It is found from Figs. 1–4 that the most influential propagation parameter is the path loss decay factor. Over all propagation parameter regions considered herein, widening the spreading bandwidth increases the capacity.

4. Conclusions

This paper evaluated by computer simulation the DS-

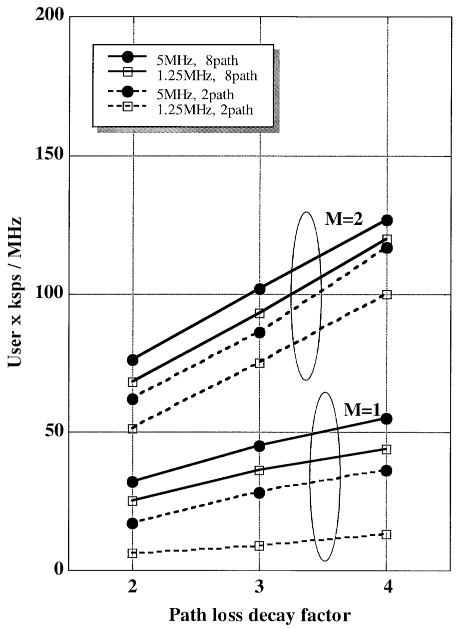

Fig. 4 Capacity dependency on α. $\rho = 0.5$, $\sigma = 8\,\mathrm{dB}$.

CDMA power controlled reverse link capacities, expressed in ksps/cell/MHz, two spreading bandwidths, 1.25 MHz and 5 MHz, taking into account the various propagation channel parameters (path loss decay factor, shadowing standard deviation, shadowing correlation and the number of resolved paths) and antenna diversity reception. We found that the capacity increase achieved by increasing the spreading bandwidth from 1.25 MHz to 5 MHz was 43% for 8 ksps transmission but only 56% for 64 ksps transmission. Therefore, we should be careful when estimating the link capacity for the case of mixed voice/data services. It was also found, as anticipated from [11], that the most influential propagation parameter is the path loss decay factor; this suggests that DS-CDMA capacity depend strongly on the type of area, e.g., urban area, suburban area, and hilly area.

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