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Downlink Site Selection Transmit Diversity with Power Allocation for A 2-dimensional Block Spread DS-CDMA Cellular System

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Abstract-**2-dimensional (2D) block spread direct sequence-code division multiple access (DS-CDMA) allows mutli-rate/mutli-connection without causing downlink multi-access interference (MAI) in the presence of a frequency-selective fading channel. However, in a cellular system, the inter-cell interference remains. The site selection diversity transmission (SSDT) can be used to reduce the inter-cell interference and increase the downlink capacity. In this paper, we show that if adaptive power allocation is applied, where the BS allocates different power levels to different users according to their channel conditions, 2D block spread DS-CDMA with SSDT provides larger downlink capacity than the conventional DS-CDMA with SSDT.**

I. INTRODUCTION

Recently, we have proposed 2-dimensional (2D) block spreading using orthogonal variable spreading factor (OVSF) codes [T1] for quasi-synchronous uplink transmission as well as downlink transmission [2]. 2D block spreading makes it possible to realize multi-rate transmission while avoiding sophisticated multiuser detection (MUD). However, so far, only single-cell environment was considered in [2]-[4]. In a cellular system, 2D block spread DS-CDMA can only remove intra-cell interference but still suffers from inter-cell interference. Therefore, the interference reduction and the power control are essential methods to increase the system capacity as well as to decrease the transmit power.

As discussed in [6]-[8], the downlink power control takes the form of power allocation at the BS transmitter according to different users' channel conditions in a given cell. Kim [5] proposed a power control algorithm for adjusting cell-site powers as well as allocating them to users in a CDMA cellular system using site selection diversity transmission (SSDT). SSDT was proposed to increase the downlink capacity [5] and found to be the optimal solution for downlink handoff from the viewpoint of power efficiency [8].

In this paper, we consider the impact of the power allocation under the total power constraint on the downlink capacity. We address the question about whether the joint use of power allocation and SSDT can increase the downlink capacity of a 2D block spread DS-CDMA cellular system. The remainder of this paper is organized as follows. Sect. II presents the downlink transmission model of a cellular 2D block spread DS-CDMA using SSDT and power allocation. We also derive an expression for the received signal-to-interference plus noise power ratio (SINR) of 2D block spread DS-CDMA with different power allocation algorithms. Using the derived SINR, the outage probability is evaluated by Monte-Carlo numerical computation method in Sect. III. Sect. IV offers some conclusions.

II. DOWNLINK TRANSMISSION WITH SSDT

We consider a simple cellular system model consisting of 19 identical hexagonal cells. The center cell is the cell of interest. We assume an interference-limited system, where the effect of the background noise can be neglected compared with MAI. The BS is located at the center of each cell. An omni transmit antenna is assumed for all BS's. Here, we assume a square-root Nyquist chip shaping filter at the transmitter and the same filter at the receiver as a chip-matched filter. Ideal chip sampling timing is assumed at the receiver. Therefore, a chip-spaced discrete-time signal representation is used throughout the paper.

A. 2D block spread DS-CDMA

A downlink transmission model is illustrated in Fig. 1, where U users are communicating with each BS. In this paper, c (=0~18) and u (=0~U–1) denote the cell index and MS index, respectively. The uth user in the cth cell is denoted by $u(c)$. We consider block data transmission of $N_c/SF^f_{u(c)}$ symbols. The $u(c)$th user's data symbol vector, $\mathbf{d}_{u(c)}=\left[d_{u(c)}(0),\ldots,d_{u(c)}(N_c/SF^f_{u(c)}-1)\right]^T$, is spread by a 2D block orthogonal spreading code matrix $\mathbf{C}_{u(c)}$. As shown in Fig. 2, the size of $\mathbf{C}_{u(c)}$ is $SF^t_{u(c)}\times SF^f_{u(c)}$ and the overall spreading factor is $SF_{u(c)}=SF^t_{u(c)}\times SF^f_{u(c)}$. $\mathbf{C}_{u(c)}$ is given by

$$\mathbf{C}_{u(c)}=\mathbf{c}^t_{u(c)}\left(\mathbf{c}^f_{u(c)}\right)^T \tag{1}$$

with $\mathbf{c}^t_{u(c)}$ and $\mathbf{c}^f_{u(c)}$ being the column and row orthogonal spreading codes, respectively, given by

$$\begin{cases}\mathbf{c}^t_{u(c)}=\left[c^t_{u(c)}(0),\ldots,c^t_{u(c)}(SF^t_{u(c)}-1)\right]^T\\ \mathbf{c}^f_{u(c)}=\left[c^f_{u(c)}(0),\ldots,c^f_{u(c)}(SF^f_{u(c)}-1)\right]^T\end{cases}, \tag{2}$$

where the superscript T denotes the transposition. The resulting 2D block spread signal can be expressed using the $SF^t_{u(c)}\times N_c$ matrix $\mathbf{S}_{u(c)}$ as

$$\mathbf{S}_{u(c)}=\mathbf{C}_{u(c)}\otimes\left(\mathbf{d}_{u(c)}\right)^T, \tag{3}$$

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where $\otimes$ denotes the Kronecker product.

Chips from $\mathbf{S}_{u(c)}$ are read out row-by-row over an $SF^{t}_{u(c)}$-block period, where N_c chips are transmitted in each block, and the resultant sequence is multiplied by a cell-specific scrambling code. Next, cyclic prefix (CP) insertion into the guard interval (GI) follows to avoid inter-block interference (IBI). Finally, different users' signals are code-multiplexed. The multicode downlink spread signal can be expressed using an equivalent baseband signal representation as

$$\hat{\mathbf{s}}_c = \sqrt{2P_{T,c}} \sum_{u=0}^{U-1} \sqrt{\Phi_{c\_u(c)}} \left[\left(\tilde{\mathbf{x}}_{u(c)}(0)\right)^T, \cdots, \left(\tilde{\mathbf{x}}_{u(c)}(SF^t_{u(c)}-1)\right)^T \right]^T, \quad (4)$$

where $P_{T,c}$ denotes the cth BS's total transmit power, $\Phi_{c\_u(c)} = P_{T,c\_u(c)} / P_{T,c}$ is a fraction of the transmitted power allocated to the $u(c)$th user with $\sum_{u=0}^{U-1} \Phi_{c\_u(c)} = 1$. $\tilde{\mathbf{x}}_{u(c)}(m)$ is given by

$$\begin{aligned} \tilde{\mathbf{x}}_{u(c)}(m) = c^{scr}_c(t;m) c^t_{u(c)}(m) [& b_{u(c)}(N_c - N_g), \cdots, \\ & b_{u(c)}(N_c - 1), b_{u(c)}(0), \cdots, b_{u(c)}(N_c - 1)]^T, \end{aligned} \quad (5)$$

where $c^{scr}_c(t;m)$ is the cth cell's scrambling code for the mth block data with $\left|c^{scr}_c(t;m)\right| = 1$, N_g is the GI length, and $b_{u(c)}(n)$ is given by

$$b_{u(c)}(n) = c^f_{u(c)}(n \bmod SF^f_{u(c)}) d_{u(c)}\left(\left\lfloor n / SF^f_{u(c)} \right\rfloor\right), \quad (6)$$

with $\lfloor x \rfloor$ being the largest integer smaller than or equal to x.

Without loss of generality, we assume that the 0(0)th user is the desired user. A superposition of 18 cells' faded signals is received by the 0(0)th user. The received signal vector with length $SF^t_{0(0)}(N_c + N_g)$ can be represented as

$$\mathbf{r}_{0(0)} = \sum_{c=0}^{18} \sqrt{A_{c\_0(0)}} \tilde{\mathbf{H}}_{c\_0(0)} \hat{\mathbf{s}}_c + \boldsymbol{\mu}, \quad (7)$$

where $\tilde{\mathbf{H}}_{c\_0(0)}$ is the channel matrix over an $SF^t_{u(c)}$-block transmission interval, $\boldsymbol{\mu}$ is the noise vector due to the additive white Gaussian noise (AWGN) with zero-mean and variance of $2N_0/T_c$ (N_0 is the one-sided power spectrum density) and $A_{c\_0(0)}$ is given by

$$A_{c\_0(0)} = r^{-\beta}_{c\_0(0)} 10^{-0.1\eta_{c\_0(0)}} \quad (8)$$

with $r_{c\_0(0)}$ being the distance between the cth BS and the 0(0)th MS, β the path loss exponent, and $\eta_{c\_0(0)}$ the lognormal shadowing loss [9]. We assume an L-path block fading channel having an exponential power delay profile

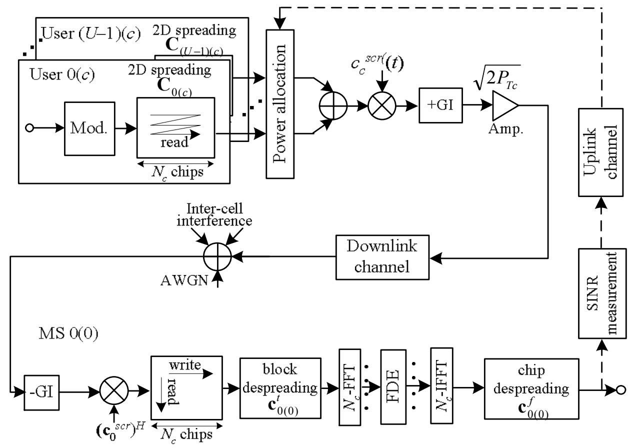

Fig. 1. Downlink transmission model.

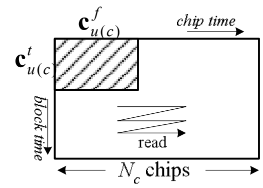

Fig. 2. 2D block spreading.

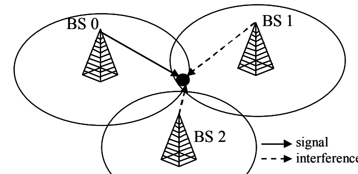

Fig. 3. SSDT.

with path gains $\{h_{c\_u(c),l};\ l=0\sim L-1\}$, time delays $\{\tau_{c\_u(c),l};\ l=0\sim L-1\}$ and maximum Doppler frequency f_D. Block fading means that the path gains $\{h_{c\_u(c),l}\}$ stay constant over one block interval $T=T_c(N_c+N_g)$, but vary block-by-block. The mth block channel gain is denoted as $h_{c\_u(c),l}(m)$ and $E[|h_{c\_u(c),l}(m)|^2]=A\alpha^{-l}$, where $A=(1-\alpha^{-1})/(1-\alpha^{-L})$ ($E[\cdot]$ is the ensemble average operation). $\tau_{c\_u(c),l}$ is assumed to be $\tau_{c\_u(c),l}=\tau_c+l$, where τ_c is the cth BS's timing offset and the maximum time delay is assumed to be shorter than the GI. $\tilde{\mathbf{H}}_{c\_0(0)}$ can be expressed as

$$\tilde{\mathbf{H}}_{c\_u(c)} = diag\left\{\mathbf{H}_{c\_u(c)}(0), \ldots, \mathbf{H}_{c\_u(c)}(SF^t_{u(c)}-1)\right\}, \quad (9)$$

where $\mathbf{H}_{c\_u(c)}(m)$ is the mth block $(N_c+N_g)\times(N_c+N_g)$ circulant Toeplitz channel matrix and its first column is given by [9]

$$\mathbf{h}_{c\_u(c)}(m) = [h_{c\_u(c),0}(m), \ldots, h_{c\_u(c),L-1}(m), 0, \ldots, 0]^T. \quad (10)$$

B. SSDT

Assuming that all BS's transmit their pilot signals with equal power, a mobile user measures the local average received signal power from its surrounding BS's and sorts them out in the descending order [8]. Based on the measurement of $P_{T,c}A_{c\_0(0)}$, we have the ranking as

$$P_{T,0}A_{0\_0(0)} > \cdots > P_{T,(C-1)}A_{(C-1)\_0(0)} > 0. \quad (11)$$

Without loss of generality, the BS index is given in a descending order. In SSDT, only the strongest BS is selected for each user as shown in Fig. 3 [6].

C. Power Allocation

The downlink power control presented in [5]-[8] allocates different powers to different users according to their channel conditions under the total transmitted power constraint. In this paper, we assume that each BS has the same constant transmit power and consider two kinds of power allocation: one is equal power allocation, $\Phi^{equal}_{c\_u(c)} = 1/U$, and the other is adaptive power control, $\Phi^{adap.}_{c\_u(c)}$. The latter needs the feedback estimated channel quality $\{A_{c\_u(c)}\}$ from MS's and then allocates the limited cell-site power $P_{T,c}$ according to $\{A_{c\_u(c)}\}$ so that all the MS's enjoy equal link quality (i.e., the same target SINR for all users). In this paper, we assume ideal feedback (no delay and error).

A balanced link quality is achieved by solving the link quality balancing problem to find the individual normalized power ratio, $\Phi^{adap.}_{c\_u(c)}$, to maximize the minimum transmission quality among $\{u(c);\ u=0\sim U-1\}$ [5]. $\Phi^{adap.}_{c\_u(c)}$ is given by

$$\Phi^{adap.}_{c\_u(c)} = \left(\sum_{c'=1}^{18} \frac{A_{c'\_u(c)}}{A_{c\_u(c)}}\right) \Bigg/ \left(\sum_{c'=1}^{18}\sum_{u'=0}^{U-1} \frac{A_{c'\_u'(c)}}{A_{c\_u'(c)}}\right). \tag{12}$$

It is clear that adaptive power allocation makes a user who experiences less inter-cell interference require less transmit power $\Phi^{adap.}_{c\_u(c)} P_{T,c}$. $\Phi^{adap.}_{c\_u(c)}$ should be allocated to the $u(c)$th user from the cth cell to achieve higher SINR than the required SINR λ_{req}, which is set as [6]

$$\lambda_{req} = \gamma_t / \chi, \tag{13}$$

where γ_t is target SNR and χ represents the allowable interference rise factor, defined as the interference plus background noise-to-background noise power ratio.

If the power difference between different users is limited to B_{limit}, the power-limited adaptive power allocation is represented as

$$\Phi^{\text{limit}}_{c\_u(c)} = \begin{cases} \Phi^{equal}_{c\_u(c)} \cdot B_{\text{limit}}, & \Phi^{adap.}_{c\_u(c)} > \Phi^{equal}_{c\_u(c)} \cdot B_{\text{limit}} \\ \Phi^{equal}_{c\_u(c)} / B_{\text{limit}}, & \Phi^{adap.}_{c\_u(c)} < \Phi^{equal}_{c\_u(c)} / B_{\text{limit}} \\ \Phi^{adap.}_{c\_u(c)}, & otherwise \end{cases}. \tag{14}$$

D. BER

At the receiver, the received signal is sampled at the chip rate and the GI is removed first. The GI-removed received signal is written row-by-row into an interleaver of size $SF^t_{0(0)} \times N_c$ and the interleaver output is despread by using the 0th BS's scrambling code $\mathbf{c}^{scr}_0(t) = [c^{scr}_0(t;0),\ldots, c^{scr}_0(t;SF^t_{0(0)}-1)]^T$ and $\mathbf{c}^t_{0(0)}$ as

$$\hat{\mathbf{r}}_{0(0)} = \sum_{c=0}^{18} \sqrt{2P_{T,c}A_{c\_0(0)}}\,\hat{\mathbf{H}}_{c\_0(0)} \sum_{u=0}^{U-1} \sqrt{\Phi_{c\_u(c)}}\,\mathbf{b}_{u(c)} + \hat{\boldsymbol{\mu}}, \tag{15}$$

where $\mathbf{b}_{u(c)} = [\mathbf{b}_{u(c)}(0),\ldots,\mathbf{b}_{u(c)}(N_c-1)]^T$ is the chip signal vector, $\hat{\boldsymbol{\mu}} = [\hat{\mu}(0),\ldots,\hat{\mu}(N_c-1)]^T$ is the noise vector with each element being an independent zero-mean complex Gaussian variable with variance $2N_0/T_c/SF^t_{0(0)}$ and $\hat{\mathbf{H}}_{c\_u(c)}$ is the $N_c \times N_c$ channel matrix, given by

$$\hat{\mathbf{H}}_{c\_u(c)} = \frac{1}{SF^t_{0(0)}} \sum_{m=0}^{SF^t_{0(0)}-1} \mathbf{H}_{c\_0(0)}(m) \times \left(c^{scr}_0(t;m)c^t_{0(0)}(m)\right)^* c^{scr}_c(t;m)c^t_{u(c)}(m). \tag{16}$$

If the channel changes slowly (i.e., $\mathbf{H}_{c\_u(c)}(m) \approx \mathbf{H}_{c\_u(c)}(0)$ for $m = 0 \sim SF^t_{0(0)}-1$) and orthogonal OVSF codes $\{\mathbf{c}^t_{u(0)}\}$ are used, we have

$$\hat{\mathbf{H}}_{c\_u(c)} = \begin{cases} \mathbf{H}_{0\_0(0)}(0), & \text{if } c = u = 0 \\ \mathbf{0}_{N_c}, & \text{if } c = 0, u \neq 0 \end{cases}, \tag{17}$$

where $\mathbf{0}_{N_c}$ is an $N_c \times N_c$ zero matrix. Therefore, the intra-cell interference is removed using simple block despreading [2].

After block despreading, one-tap FDE is carried out to obtain

$$\underline{\mathbf{y}}_{0\_0(0)} = \left(\underline{\hat{\mathbf{W}}}_{0\_0(0)}\right)^H \mathbf{F}\hat{\mathbf{r}}_{0(0)}, \tag{18}$$

where $\mathbf{F}$ is the $N_c \times N_c$ fast Fourier transform (FFT) matrix with the xth row and yth column element given by $F_{x,y} = (1/\sqrt{N_c})\exp(-j2\pi xy/N_c)$, $\underline{\hat{\mathbf{W}}}_{0\_0(0)}$ is the $N_c \times N_c$ diagonal FDE weight matrix according to the minimum mean square error (MMSE) criterion, and the superscript H denotes the Hermitian transposition. $\underline{\hat{\mathbf{W}}}_{0\_0(0)}$ is given by

$$\underline{\hat{\mathbf{W}}}_{0\_0(0)} = \frac{\sqrt{\Phi_{0\_0(0)}}\,\underline{\hat{\mathbf{H}}}_{0\_0(0)}}{\left[\begin{array}{l} \Phi_{0\_0(0)}\left\|\underline{\hat{\mathbf{H}}}_{0\_0(0)}\right\|^2 + \sum_{c=1}^{18} \frac{A_{c\_0(0)}}{A_{0\_0(0)}}\left\|\underline{\hat{\mathbf{H}}}_{c\_0(0)}\right\|^2 \\ + (N_0/T_c)/(SF^t_{0(0)}P_{T,0}A_{0\_0(0)})\mathbf{I}_{N_c} \end{array}\right]} \tag{19}$$

with $\underline{\hat{\mathbf{H}}}_{c\_u(c)} = \mathbf{F}\hat{\mathbf{H}}_{c\_u(c)}\mathbf{F}^H$, where $\|\mathbf{A}\|^2 = \mathbf{A}^H\mathbf{A}$ is the norm of matrix $\mathbf{A}$ and $\mathbf{I}_{N_c}$ is an $N_c \times N_c$ identity matrix.

Next, the $N_c \times N_c$ inverse Fourier transform matrix (IFFT) $\mathbf{F}^H$ is multiplied to $\underline{\mathbf{y}}_{0\_0(0)}$ and the 2nd despreading using $\mathbf{c}^f_{0(0)}$ is performed to get the decision variable vector as

$$\hat{\mathbf{d}}_{0(0)}(n)=\frac{1}{SF^{f}_{0(0)}}diag\{\underbrace{\left(\mathbf{c}^{f}_{0(0)}\right)^{H},\ldots,\left(\mathbf{c}^{f}_{0(0)}\right)^{H}}_{N_c/SF^{f}_{0(0)}}\}\mathbf{F}^{H}\underline{\mathbf{y}}_{0\_0(0)}\ . \quad (20)$$

If the channel is time-invariant over at least $SF^{t}_{0(0)}$-block duration, there is no intra-cell interference but only the self interference and inter-cell interference. Assuming that the interferences can be approximated as independent zero-mean Guassian variables, the signal-to-interference plus noise ratio (SINR) λ of 2D block spread DS-CDMA downlink with SSDT can be expressed as

$$\lambda=\frac{2SF_{0(0)}\Phi_{0\_0(0)}}{\left[\begin{array}{l}\Phi_{0\_0(0)}SF^{t}_{0(0)}(\hat{\varepsilon}_0-1)+SF^{t}_{0(0)}\sum_{c=1}^{18}\hat{\varepsilon}_c\,A_{c\_0(0)}/A_{0\_0(0)}\\+\left(N_0/T_c\right)/\left(P_{T,0}A_{0\_0(0)}\right)\hat{\varepsilon}_{noise}\end{array}\right]} \quad (21)$$

with

$$\begin{cases}\hat{\varepsilon}_c=\overline{tr}\left(\left\|\left(\hat{\underline{\mathbf{W}}}_{0\_0(0)}\right)^{H}\hat{\underline{\mathbf{H}}}_{c\_0(0)}\right\|^{2}\right)\Big/\left(\overline{tr}\left(\left(\hat{\underline{\mathbf{W}}}_{0\_0(0)}\right)^{H}\hat{\underline{\mathbf{H}}}_{0\_0(0)}\right)\right)^{2}\\ \hat{\varepsilon}_{noise}=\overline{tr}\left(\left\|\hat{\underline{\mathbf{W}}}_{0\_0(0)}\right\|^{2}\right)\Big/\left(\overline{tr}\left(\left(\hat{\underline{\mathbf{W}}}_{0\_0(0)}\right)^{H}\hat{\underline{\mathbf{H}}}_{0\_0(0)}\right)\right)^{2}\end{cases}, \quad (22)$$

where $\overline{tr}(\mathbf{A})=\left(1/N_c\right)tr(\mathbf{A})$ is the normalized trace of an $N_c\times N_c$ matrix $\mathbf{A}$. The conventional DS-CDMA is a special case of 2D block spread DS-CDMA with $SF^{t}_{u(c)}\times SF^{f}_{u(c)}=1\times SF_{u(c)}$. In spite of the self interference with variance of $\Phi_{c\_u(c)}(\hat{\varepsilon}_c-1)$, there is the intra-cell interference with variance of $(1-\Phi_{c\_u(c)})(\hat{\varepsilon}_c-1)$. Therefore, the SINR of the conventional DS-CDMA is given by

$$\lambda=\frac{2SF_{0(0)}\Phi_{0\_0(0)}}{\left[(\hat{\varepsilon}_0-1)+\sum_{c=1}^{18}\hat{\varepsilon}_c\frac{A_{c\_0(0)}}{A_{0\_0(0)}}+\frac{N_0/T_c}{P_{T,0}A_{0\_0(0)}}\hat{\varepsilon}_{noise}\right]}\ . \quad (23)$$

If the code assignment of 2D block spreading is set as $SF^{t}_{u(c)}\times SF^{f}_{u(c)}=U\times(SF_{u(c)}/U)$ and the equal power allocation is used as $\Phi^{equal}_{c\_u(c)}=1/U$, the SINR of the conventional DS-CDMA is exactly the same as that of 2D block spread DS-CDMA. However, if the adaptive power allocation is used, the SINR of the conventional DS-CDMA is different from that of 2D block spread DS-CDMA.

Assuming QPSK data-modulation, the conditional BER for the given sets of $\{\mathbf{H}_{c\_0(0)};\ c=0\sim18\}$ and $\{A_{c\_0(0)};\ c=0\sim18\}$ is given by [10]

$$P_b(\lambda)=0.5erfc\sqrt{\lambda/4}\ , \quad (24)$$

where $erfc(\cdot)$ is the complementary error function. The target SINR $\lambda_{\rm req}$ for the given required BER is obtained from Eq. (13). The average BER of uncoded DS-CDMA can be numerically evaluated by averaging Eq. (24) over all possible $\{\mathbf{H}_{c\_0(0)}\}$ and $\{A_{c\_0(0)}\}$.

III. NUMERICAL RESULTS AND DISCUSSION

In this paper, we assume that each user has the same overall spreading factor of 2D OVSF spreading codes, which is equal to $SF=SF^{t}_{u(c)}\times SF^{f}_{u(c)}$, to keep the same data rate. As for the 2D block spreading code assignment [2], we assign all users to use $SF^{t}_{u(c)}=2^{k}$ if $U=2^k$ (k=0,1,…). If $2^{k-1}<U<2^k$, (2^k-U) users among U users can be assigned $SF^{t}_{u(c)}=2^{k-1}$ and then the other $(2U-2^k)$ users can use $SF^{t}_{u(c)}=2^{k}$. By doing so, all U users' codes are orthogonal if $U<SF$ is satisfied. We calculate the average SINR of all U users per cell for 2D block spread DS-CDMA downlink.

Employing Monte Carlo numerical method, the downlink capacity is evaluated. The local BER averaged over the multipath fading statistics is obtained for 2D block spread DS-CDMA with FDE. The probability of this BER failing to achieve the required BER is defined as the outage probability. The link capacity is defined as the maximum normalized number of supportable users while keeping the outage probability lower than or equal to allowable outage probability. Table 1 shows the numerical simulation conditions. It is assumed that the shadowing loss and the location of each MS remain invariant during communication (the user mobility is not considered). We assume QPSK modulation, N_c=256 and N_g=32 and a required BER of 10^{-2}. The maximum number of users just before exceeding the allowable outage probability of 0.1 is the link capacity.

Table 1. Numerical simulation condition

Modulation scheme	QPSK
Cellular structure	C=19 hexagon cells
User distribution	Uniform
Interference rise factor	χ=0~6dB
Path loss exponent	β=3.5
Standard deviation of shadowing loss	σ=6dB
Multipath fading channel	L-path Rayleigh fading
Equalization	MMSE-FDE
Required BER	$BER_{req}=10^{-2}$
Required outage probability	$Q_0=10^{-1}$

A. *Comparison between 2D block spread DS-CDMA and conventional DS-CDMA*

Fig. 4 compares the downlink capacity of 2D block spread DS-CDMA using power allocation without power limit with that of the conventional DS-CDMA as a function of the interference rise factor χ. We can see that as χ increases, the downlink capacity increases. If the equal power allocation is used, 2D block spread DS-CDMA performs the same as the conventional DS-CDMA. However, the use of adaptive power allocation increases the downlink capacity of 2D block spread DS-CDMA but slightly decreases that of the conventional DS-CDMA. The difference between the conventional and 2D block spread DS-CDMA comes from the different impact of the adaptive power allocation on intra-cell interference. In 2D block spread DS-CDMA, the intra-cell interference can be removed completely. The adaptive power allocation provides more power to a user who receives larger inter-cell interference (i.e., closer to the cell edge) and thus improves its SINR. However, for the conventional DS-CDMA, this user's large power results in large intra-cell interference to other users in the same cell, which decreases other users' SINRs. Therefore, this simple adaptive power allocation increases the probability of the SINR λ of the conventional DS-CDMA falling below λ_{req}, resulting in higher outage probability.

B. *Impact of the power limit*

Next, we use the power-limited adaptive power allocation. Fig. 5 shows the impact of the power limit on the link capacity of 2D block spread DS-CDMA when χ=4dB. When B_{limit}=0dB, the adaptive power allocation reduces to the equal power allocation and 2D block spread DS-CDMA provides the same downlink capacity as that of conventional DS-CDMA. However, as B_{limit} increases, the link capacity of 2D block spread DS-CDMA with adaptive power allocation increases to 0.25 (when B_{limit}=2dB) and stays constant (B_{limit}>2dB), since adaptive power allocation can improve the SINR of a user who suffers from large inter-cell interference. The link capacity of conventional DS-CDMA also increases, however, it decreases when B_{limit} is bigger than 3dB. This is because larger power results in larger intra-cell interference, which decreases other users' SINRs. When B_{limit} is infinite (corresponding to the case without power limit), the adaptive power allocation provides larger downlink capacity than equal power allocation for 2D block spread DS-CDMA; however, the adaptive power allocation yields worse performance for conventional DS-CDMA.

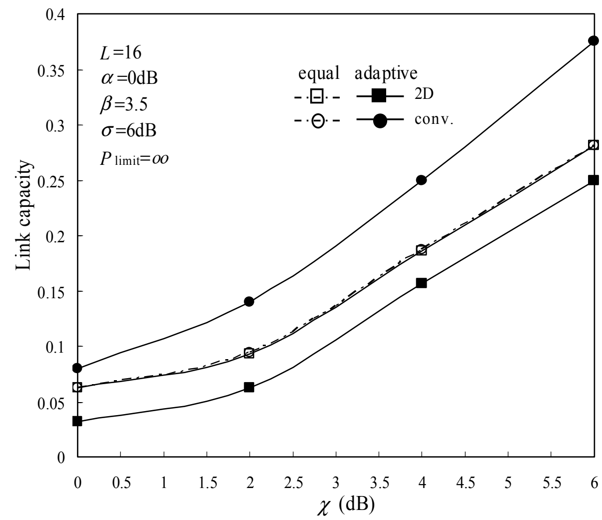

Fig. 4. Link capacity as a function of the interference rise factor χ.

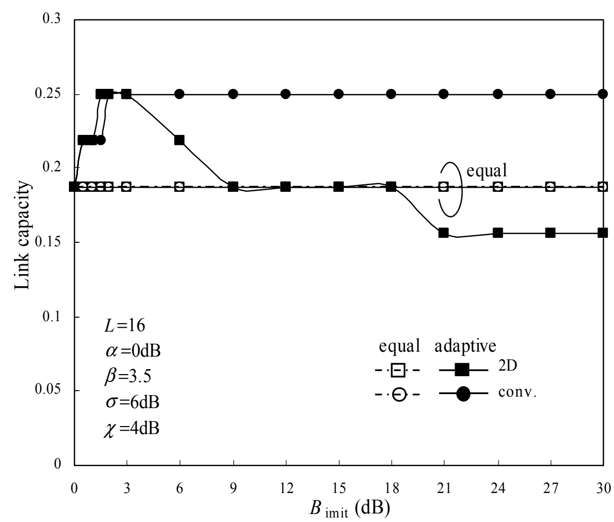

Fig. 5. Link capacity as a function of the power limit.

IV. CONCLUSION

In this paper, we discussed the multi-cell downlink capacity of 2D block spread DS-CDMA with site selection diversity transmission (SSDT). Since there is no intra-cell interference in 2D block spread DS-CDMA, the adaptive power allocation improves the SINR by allocating more power to a user who receives larger inter-cell interference. It was shown that with adaptive power allocation, 2D block spread DS-CDMA with SSDT provides larger downlink capacity than the conventional DS-CDMA with SSDT.

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