A Power-controlled 2-dimensional Block Spread DS-CDMA Cellular System with Uplink Site Selection Diversity

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***Abstract*—2-dimensional (2D) block spread direct sequence-code division multiple access (DS-CDMA) allows uplink mutli-rate/mutli-connection transmissions without causing a serious 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 (SSD) can be used to reduce the inter-cell interference and increase the uplink capacity. Furthermore, transmit power control (TPC) is necessary to combat the near-far problem. In this paper, we discuss the impact of SSD and TPC on the uplink capacity of 2D block spread DS-CDMA and compare it with those of conventional DS-CDMA and 1D block spread DS-CDMA.**

Keywords-2-dimensional (2D) block spreading, MAI, SSD, TPC, DS-CDMA, uplink transmission.

I. INTRODUCTION

In the next generation mobile networks, high data-rate services are demanded [1], [2]. The high data-rate services need more power than current voice-dominated services, and thus interference also gets strong. A code division multiple access (CDMA) system is interference-limited. Therefore, the interference power reduction and the power control are essential methods to increase the system capacity.

Conventional DS-CDMA needs a sophisticated multiuser detection (MUD) technique to suppress multi-access interference (MAI). Recently, 1-dimensional (1D) block spreading was proposed in [3], [4] to remove MAI through simple block despreading. Block despreading converts an MUD problem into a set of equivalent single-user equalization problems [3], [4]. More recently, we have proposed 2-dimensional (2D) block spreading using orthogonal variable spreading factor (OVSF) spreading codes [5] for quasi-synchronous uplink transmission [6], [7]. 2D block spreading makes it possible to remove the MAI as well as to take advantage of time- and frequency-domain channel selectivity. Conventional DS-CMDA and 1D block spread DS-CDMA are special cases of 2D block spread DS-CDMA. So far, only the single-cell uplink case was considered in [3], [4], [6] and [7]. 2D block spread DS-CDMA can only remove the intra-cell interference. The uplink of 2D block spread DS-CDMA still suffers from the inter-cell interference.

In a DS-CDMA cellular system, uplink transmit power control (TPC) is used to combat the well-known near-far problem and to reduce the adverse effect of multipath fading [11], [12]. Fast TPC is used to always keep the transmit power at a minimum required value [13]. This results in increased capacity by reducing the interference to other users in the other cells as well as the own cell.

Site selection diversity (SSD) is an essential technique together with fast TPC to reduce the performance degradation due to multipath fading and shadowing for a user near the cell edge [13]. In the uplink SSD, a received data sequence obtained after channel equalization and despreading at each BS is transferred to the radio network controller (RNC) via the backhaul [13] and the transferred data sequences with the maximum received power is selected. The use of SSD can reduce the inter-cell interference and increase the uplink capacity [8]-[10].

In this paper, we consider the impact of SSD and TPC on the uplink capacity of a 2D block spread DS-CDMA cellular system. We address a question about whether the joint use of TPC and SSD can increase the uplink capacity of a 2D block spread DS-CDMA cellular system.

The remainder of this paper is organized as follows. Sect. 2 presents the uplink system model of a 2D block spread DS-CDMA cellular system with SSD and TPC. We derive an expression for the received signal-to-interference plus noise power ratio (SINR) in Sect. 3. Using the derived SINR expression, the outage probability of 2D block spread DS-CDMA is evaluated by a Monte-Carlo numerical computation method and compared with those of 1D block spread and conventional DS-CDMA in Sect. 4. Sect. 5 offers conclusions.

II. UPLINK SYSTEM MODEL

We consider a simple cellular system model consisting of 19 identical hexagonal cells. To compute the interference power, the 18 nearest co-channel cells are considered since they are the predominant cause of inter-cell interferences [11]. The BS is located at the center of each cell. A single omni transmit antenna is assumed for all BS's. An uplink system model is illustrated in Fig. 1, where different users' signals go through different channels and are received by the BS's. Here, we assume the 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, the chip-spaced discrete-time signal representation is used throughout the paper. In this paper, bold upper-case letters denote matrices, and bold lower-case letters stand for column vectors. The *u*th user in the *c*th cell is denoted by *u*(*c*). Without loss of generality, we assume that the 0(0)th user is the desired user.

A. Site Selection Diversity

Assuming that each MS transmits a pilot signal periodically, each BS measures the pilot power and sends it to RNC, as shown in Fig. 2. The RNC sorts them out in a descending order for selection of active BS's [9]. We consider two types of SSD: slow SSD and fast SSD.

For slow SSD, the BS's are ranked based on the measurement of the local average pilot power $\{P_{T,0(0)}A_{0(0)\_c}\}$, where $P_{T,(0)0}$ denotes the 0(0)'s user's transmit pilot power and $A_{0(0)\_c}$ is given by

$$A_{0(0)\_c} = r_{0(0)\_c}^{-\beta}10^{-0.1\eta_{0(0)\_c}} \tag{1}$$

with $r_{0(0)\_c}$ being the distance between the 0(0)th MS and the *c*th BS, β the path loss exponent, and $\eta_{0(0)\_c}$ the lognormal shadowing loss with zero mean and variance $2\sigma^2$ [11]. Without loss of generality, the BS index is given in a descending order as

$$P_{T,0(0)}A_{0(0)\_0} > P_{T,0(0)}A_{0(0)\_1} > \cdots > 0\,. \tag{2}$$

Only the BS with the strongest pilot power is selected by RNC [10].

For fast SSD, the BS's are ranked based on instantaneous pilot power including the variations due to multipath fading as well as the distance-dependent path loss and shadowing loss. We assume an *L*-path block fading channel with path gains $\{h_{0(0)\_c,l}(t);\ l=0\sim L-1\}$ and time delays $\{\tau_{0(0)\_c,l};\ l=0\sim L-1\}$. The block fading means that path gains $\{h_{0(0)\_c,l}\}$ stay constant over one block interval $T=T_c(N_c+N_g)$, but vary block-by-block. The *m*th block channel gain is denoted by $h_{0(0)\_c,l}(m)$ and $E[|h_{0(0)\_c,l}(m)|^2]=(1-\alpha^{-1})/(1-\alpha^{-L})\alpha^{-l}$ ($E[\cdot]$ is the ensemble average operation). According to the measured pilot power at the *m*th block $\{P_{T,0(0)}A_{0(0)\_c}\sum_{l=0}^{L-1}\left|h_{0(0)\_c,l}(m)\right|^2\}$, we have

$$P_{T,0(0)}A_{0(0)\_0}\sum_{l=0}^{L-1}\left|h_{0(0)\_0,l}(m)\right|^2 > P_{T,0(0)}A_{0(0)\_1}\sum_{l=0}^{L-1}\left|h_{0(0)\_1,l}(m)\right|^2 > \cdots > 0\,. \tag{3}$$

Only the BS with the strongest instantaneous pilot power is selected by RNC.

B. 2D block spread DS-CDMA

The 2D block spreading code is a product code of two orthogonal spreading codes and is represented in a matrix form as $\mathbf{C}_{u(c)} = \mathbf{c}^t_{u(c)}(\mathbf{c}^f_{u(c)})^T$, as shown in Fig. 3, for the *u*(*c*)th user with the overall spreading factor $SF_{u(c)} = SF^t_{u(c)} \times SF^f_{u(c)}$, where $\mathbf{c}^t_{u(c)}$ and $\mathbf{c}^f_{u(c)}$ are the column and row orthogonal spreading codes, respectively, given by

$$\begin{cases}\mathbf{c}^t_{u(c)} = \left[c^t_{u(c)}(0),\ldots,c^t_{u(c)}(SF^t_{u(c)}-1)\right]^T\\ \mathbf{c}^f_{u(c)} = \left[c^f_{u(c)}(0),\ldots,c^f_{u(c)}(SF^f_{u(c)}-1)\right]^T\end{cases}, \tag{4}$$

$\mathbf{c}^t_{u(c)}$ is used to remove the MAI; up-to-as many as $SF^t_{u(c)}$ users can be multiplexed without MAI. $\mathbf{c}^f_{u(c)}$ is used to reduce the ICI after FDE is carried out.

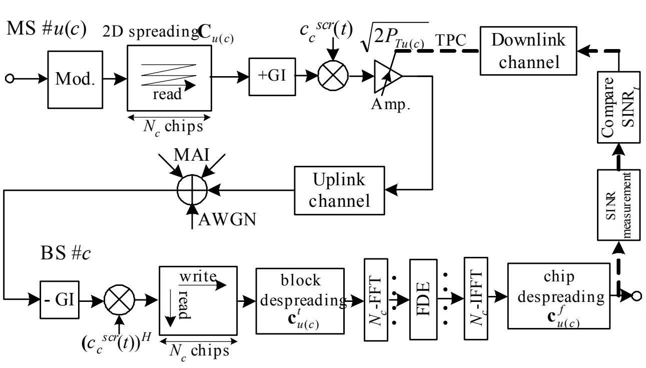

Fig. 1 Uplink transmission model.

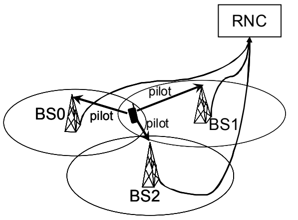

Fig. 2 Uplink SSD.

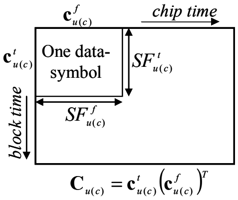

Fig. 3 2D block spreading.

We consider the block data transmission of $N_c/SF^f_{u(c)}$ data symbols for the *u*th user belonged to the *c*th cell. 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 $\mathbf{C}_{u(c)}$. The resulting 2D block spread signal can be expressed using the $SF^t_{u(c)} \times N_c$ matrix $\mathbf{S}_{u(c)}$ as

$$\mathbf{S}_{u(c)} = \mathbf{C}_{u(c)} \otimes \left(\mathbf{d}_{u(c)}\right)^T, \tag{5}$$

where ⊗ 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). The GI-inserted *u*(*c*)th user's spread signal can be expressed using an equivalent baseband signal representation as

$$\hat{\mathbf{s}}_{u(c)}=\sqrt{2P_{T,u(c)}}\left[\tilde{\mathbf{x}}_{u(c)}(0),\cdots,\tilde{\mathbf{x}}_{u(c)}(SF^{t}_{u(c)}-1)\right]^{T},\qquad(6)$$

where $P_{T,(u)c}$ denotes the $u(c)$'s user's transmit power. $\tilde{\mathbf{x}}_{u(c)}(m)$ is given by

$$\begin{aligned}\tilde{\mathbf{x}}_{u(c)}(m)=c^{scr}_{c}(t;m)c^{t}_{u(c)}(m)[&b_{u(c)}(N_c-N_g),\cdots,\\&b_{u(c)}(N_c-1),b_{u(c)}(0),\cdots,b_{u(c)}(N_c-1)]^{T}\end{aligned},\qquad(7)$$

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

$$b_{u(c)}(n)=c^{f}_{u(c)}(n\bmod SF^{f}_{u(c)})d_{u(c)}(\lfloor n/SF^{f}_{u(c)}\rfloor)\qquad(8)$$

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

At the 0th BS, a superposition of all the users' faded signals is received. The received signal vector $\mathbf{r}_0$ can be represented as

$$\mathbf{r}_0=\sum_{c}\sum_{u=0}^{U_c-1}\sqrt{A_{u(c)\_0}}\tilde{\mathbf{H}}_{u(c)\_0}\hat{\mathbf{s}}_{u(c)}+\boldsymbol{\mu},\qquad(9)$$

where U_c is the number of users served by the cth BS, $\tilde{\mathbf{H}}_{u(c)\_0}$ is the channel matrix over an $SF^{t}_{u(c)}$-block transmission interval, $\boldsymbol{\mu}$ is the noise vector due to the zero-mean additive white Gaussian noise (AWGN) with the variance $2N_0/T_c$ (N_0 is the one-sided power spectrum density). $\tilde{\mathbf{H}}_{u(c)\_0}$ can be expressed as

$$\tilde{\mathbf{H}}_{u(c)\_0}=diag\left\{\mathbf{H}_{u(c)\_0}(0),\ldots,\mathbf{H}_{u(c)\_0}(SF^{t}_{u(c)}-1)\right\},\qquad(10)$$

where $\mathbf{H}_{u(c)\_0}(m)$ is a $(N_c+N_g)\times(N_c+N_g)$ circulant Toeplitz channel matrix and its first column is given by [11]

$$\mathbf{h}_{u(c)\_0}(m)=[\underbrace{0,\ldots,0}_{\tau_{u(c)\_0}},h_{u(c)\_0,0}(m),\ldots,h_{u(c)\_0,L-1}(m),\ldots,0]^{T}.\qquad(11)$$

where $\tau_{u(c)\_0}$ is the $u(c)$th MS's timing offset and the lth path time delay $\tau_{u(c)\_0,l}$ is assumed to be $\tau_{u(c)\_0,l}=\tau_{u(c)\_0}+l$. The maximum time delay is assumed to be shorter than the GI.

C. Transmit Power Control

The signal transmitted from each user experiences independent path loss, shadowing loss, and multipath fading. The TPC target is to let the received signal power be constant. We consider fast TPC, which regulates the instantaneous power variation due to multipath fading as well as the distance-dependent path loss and shadowing loss. Letting the TPC target be denoted by P_{target}, we have

$$P_{T,u(c)}=P_{target}\left\{A_{u(c)\_c}\sum_{l=0}^{L-1}\left|h_{u(c)\_c,l}(m)\right|^{2}\right\}^{-1}.\qquad(12)$$

Fast TPC needs the feedback of estimates of $\{A_{u(c)\_c}\}$ and $\{h_{u(c)\_c,l}(m)\}$ from MS's. In this paper, we assume the ideal feedback (no delay and error).

D. Bit Error Rate Analysis

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 a de-interleaver of size $SF^{t}_{0(0)}\times N_c$ and the de-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

$$\hat{\mathbf{r}}_0=\sum_{c}\sum_{u=0}^{U_c-1}\sqrt{2P_{T,u(c)}A_{u(c)\_0}}\hat{\mathbf{H}}_{u(c)\_0}\mathbf{b}_{u(c)}+\hat{\boldsymbol{\mu}},\qquad(13)$$

where $\mathbf{b}_{u(c)}=\left[\mathbf{b}_{u(c)}(0),\ldots,\mathbf{b}_{u(c)}(N_c-1)\right]^{T}$ 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 $\hat{\mathbf{H}}_{u(c)\_0}$ is the $N_c\times N_c$ channel matrix, given by

$$\begin{aligned}\hat{\mathbf{H}}_{u(c)\_0}=\frac{1}{SF^{t}_{0(0)}}&\sum_{m=0}^{SF^{t}_{0(0)}-1}\mathbf{H}_{u(c)\_0}(m)\\&\times\left(c^{scr}_{0}(t;m)c^{t}_{0(0)}(m)\right)^{*}c^{scr}_{c}(t;m)c^{t}_{u(c)}(m)\end{aligned}.\qquad(14)$$

If the channel changes slowly (i.e., $\mathbf{H}_{u(c)\_0}(m)\approx\mathbf{H}_{u(c)\_0}(0)$ for $m=0\sim SF^{t}_{0(0)}-1$) and orthogonal OVSF codes $\{\mathbf{c}^{t}_{u(0)};u=0\sim U_0-1\}$ are used, we have

$$\hat{\mathbf{H}}_{u(c)\_0}=\begin{cases}\mathbf{H}_{0(0)\_0}(0), & \text{if } c=u=0\\ \mathbf{0}_{N_c}, & \text{if } c=0,u\neq 0\end{cases},\qquad(15)$$

where $\mathbf{0}_{N_c}$ is the $N_c\times N_c$ zero matrix. Therefore, the intra-cell interference is removed by simple block despreading [7].

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

$$\underline{\mathbf{y}}_{0(0)\_0}=\underline{\hat{\mathbf{W}}}_{0(0)\_0}\mathbf{F}\hat{\mathbf{r}}_0,\qquad(16)$$

where $\mathbf{F}$ is the $N_c\times N_c$ fast Fourier transform (FFT) matrix with the xth row and yth column element being 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. $\underline{\hat{\mathbf{W}}}_{0(0)\_0}$ is given by

$$\underline{\hat{\mathbf{W}}}_{0(0)\_0}=\frac{\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\left(\underline{\hat{\mathbf{H}}}_{0(0)\_0}\right)^{H}}{\sum_{c}\sum_{u=0}^{U-1}2P_{T,u(c)}A_{u(c)\_0}\left(\underline{\hat{\mathbf{H}}}_{u(c)\_0}\right)^{H}\underline{\hat{\mathbf{H}}}_{u(c)\_0}+\frac{2N_0}{SF^{t}_{0(0)}T_c}\mathbf{I}_{N_c}}\qquad(17)$$

with $\underline{\hat{\mathbf{H}}}_{u(c)\_0}=\mathbf{F}\hat{\mathbf{H}}_{u(c)\_0}\mathbf{F}^{H}$, where $(\cdot)^{H}$ denotes the Hermitian transpose and $\mathbf{I}_{N_c}$ is the $N_c\times N_c$ identity matrix.

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

$$\hat{\mathbf{d}}_{0(0)}(n) = \frac{1}{SF^f_{0(0)}} diag\{\underbrace{\left(\mathbf{c}^f_{0(0)}\right)^H, \ldots, \left(\mathbf{c}^f_{0(0)}\right)^H}_{N_c/SF^f_{0(0)}}\}\mathbf{F}^H \underline{\mathbf{y}}_{0(0)\_0} . \quad (18)$$

If the channel is time-invariant over at least $SF^t_{0(0)}$-block duration, intra-cell interference is removed, but only the self interference and inter-cell interference remain. The signal-to-interference plus noise ratio (SINR) λ of 2D block spread DS-CDMA can be expressed as

$$\lambda = \frac{2 \cdot S}{I_{SI} + I_{Intra} + I_{Inter} + I_{Noise}} \quad (19)$$

with

$$\begin{cases} S = \left(\overline{tr}\left(\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\,\underline{\hat{\mathbf{W}}}_{0(0)\_0}\underline{\hat{\mathbf{H}}}_{0(0)\_0}\right)\right)^2 \\ I_{SI} = \frac{1}{SF^f_{0(0)}}\left[\overline{tr}\left(\left\|\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\,\underline{\hat{\mathbf{W}}}_{0(0)\_0}\underline{\hat{\mathbf{H}}}_{0(0)\_0}\right\|^2\right) - S\right] \\ I_{Intra} = \frac{1}{SF^f_{0(0)}}\sum_{u=1}^{U_0-1}\overline{tr}\left(\left\|\sqrt{2P_{T,u(0)}A_{u(0)\_0}}\,\underline{\hat{\mathbf{W}}}_{0(0)\_0}\underline{\hat{\mathbf{H}}}_{u(0)\_0}\right\|^2\right) \\ I_{Inter} = \frac{1}{SF^f_{0(0)}}\sum_{c}\sum_{u=0}^{U_c-1}\overline{tr}\left(\left\|\sqrt{2P_{T,u(c)}A_{u(c)\_0}}\,\underline{\hat{\mathbf{W}}}_{0(0)\_0}\underline{\hat{\mathbf{H}}}_{u(c)\_0}\right\|^2\right) \\ I_{Noise} = \frac{1}{SF^t_{0(0)}SF^f_{0(0)}}\frac{2N_0}{T_c}\overline{tr}\left(\left\|\underline{\hat{\mathbf{W}}}_{0(0)\_0}\right\|^2\right) \end{cases} , \quad (20)$$

where $\overline{tr}(\mathbf{A}) = (1/N_c)tr(\mathbf{A})$ is the normalized trace of an $N_c \times N_c$ matrix $\mathbf{A}$. Substituting Eq. (15) into Eq. (20), we have $I_{Intra}=0$ for 2D block spread DS-CDMA.

1D block spread DS-CDMA [3], [4] is a special case of 2D block spread DS-CDMA when $SF^t_{u(c)} \times SF^f_{u(c)} = SF_{u(c)} \times 1$. Conventional DS-CDMA is another special case of 2D block spread DS-CDMA when $SF^t_{u(c)} \times SF^f_{u(c)} = 1 \times SF_{u(c)}$. 2D block spread DS-CDMA, 1D block spread DS-CDMA and conventional DS-CDMA have the same ability to reduce the inter-cell interference $1/SF_{u(c)}$ times. However, for 1D block spread DS-CDMA, the intra-cell interference is removed but the self interference cannot be suppressed sufficiently since $SF^f_{u(c)} = 1$; while, for the conventional DS-CDMA, the intra-cell interference remains.

Assuming QPSK data-modulation and approximating the interference as a zero-mean Gaussian process, the conditional BER for the given sets of $\{\mathbf{H}_{u(c)\_0}\}$ and $\{A_{u(c)\_0}\}$ can be computed using [12]

$$P_b(\lambda) = 0.5erfc\sqrt{\lambda/4} , \quad (21)$$

where $erfc(\cdot)$ is the complementary error function. The average BER of DS-CDMA can be numerically evaluated by averaging Eq. (21) over all $\{\mathbf{H}_{u(c)\_0}\}$ and $\{A_{u(c)\_0}\}$.

III. NUMERICAL RESULTS

In this paper, we assume that transmission data rate is the same for all users; the overall spreading factor of 2D OVSF spreading codes is equal to $SF = SF^t_{u(c)} \times SF^f_{u(c)}$ for all users. As for the 2D block spreading code assignment [7], we assign the U_c users served by the cth BS orthogonal spreading sequences with $SF^t_{u(c)} = U_c$.

In the computer simulation employing the Monte Carlo numerical method, we first calculate the uplink SINR and use Eq. (21) to obtain average BER over the channel statistics. The probability of this BER failing to achieve the required BER is defined as the outage probability. The uplink 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 simulation condition. It is assumed that the shadowing loss and the location of each MS remain invariant during communication (the user mobility during the communication is not considered). Also we assume an interference-limited uplink.

Table 1. Numerical simulation condition

Modulation scheme	QPSK
Cellular structure	19 hexagon cells
User distribution	Uniform
Path loss exponent	β=3.5
Standard deviation of shadowing loss	σ=6dB
Multipath fading channel	L-path block Rayleigh fading with uniform power delay profile
Equalization	MMSE-FDE
Required BER	BER$_{req}$=10^{-2}
Required outage probability	Q_0=10^{-1}

A. Impact of SSD on the outage probability

Fig. 4 compares the outage probability of 2D block spread DS-CDMA with different SSD schemes for *SF*=256. We can see that 2D block spread DS-CDMA without SSD achieves very poor performance. When slow or fast SSD is used, the outage probability of 2D block spread DS-CDMA improves significantly. Joint use of fast SSD and fast TPC achieves the best performance. For an allowable outage probability of 0.1, the normalized uplink capacity is around 0.15, which is 5 times that of without SSD.

B. Impact of spreading factor on the outage probability

In Fig. 5, outage probability of 2D block spread DS-CDMA with fast SSD is plotted against the number U of users normalized by *SF* for various values of *SF*. It is seen that 2D block spread DS-CDMA gives almost the same link capacity irrespective of *SF*. The inter-cell interference is the most dominant factor to determine the received SINR. We can see from Eq. (20) that I_{Inter} is proportional to U_c and inversely proportional to *SF*, which results in almost the same link capacity irrespective of *SF*.

C. Comparison between of conventional, 1D block spread and 2D block spread DS-CDMA systems

Fig. 6 compares the outage probabilities of conventional DS-CDMA, 1D block spread DS-CDMA and 2D block spread

DS-CDMA as a function of the normalized number of users. Fast SSD is used. 2D block spread DS-CDMA performs better than conventional DS-CDMA, since the intra-cell interference is removed completely in 2D block spread DS-CDMA, while it remains in conventional DS-CDMA. In 1D block spread DS-CDMA, although intra-cell interference is removed, the self interference cannot be sufficiently reduced, resulting in much worse outage probability than 2D block spread DS-CDMA.

IV. CONCLUSION

In this paper, we considered a 2D block spread DS-CDMA cellular system and discussed the impact of site selection diversity (SSD) and transmit power control (TPC) on the uplink capacity. We showed by computer simulation that the joint use of TPC and SSD can significantly improve the uplink capacity of 2D block spread DS-CDMA. With the optimum code assignment, 2D block spread DS-CDMA can remove MAI as well as reduce the self-interference. Therefore, 2D block spread DS-CDMA achieves much higher uplink capacity than conventional DS-CDMA and 1D block spread DS-CDMA.

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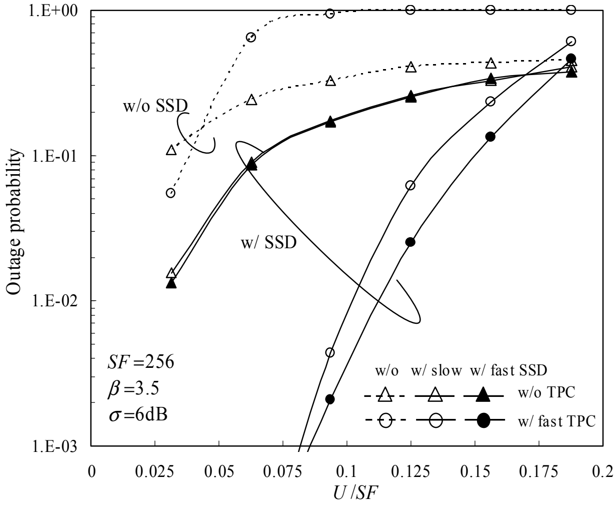

Fig. 4 Impact of SSD.

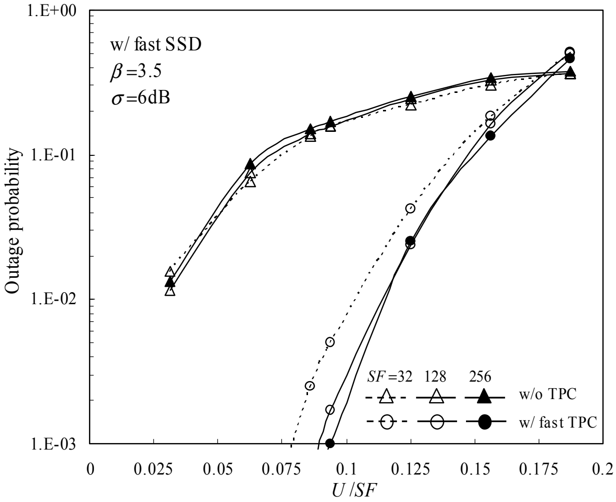

Fig. 5 Impact of *SF*.

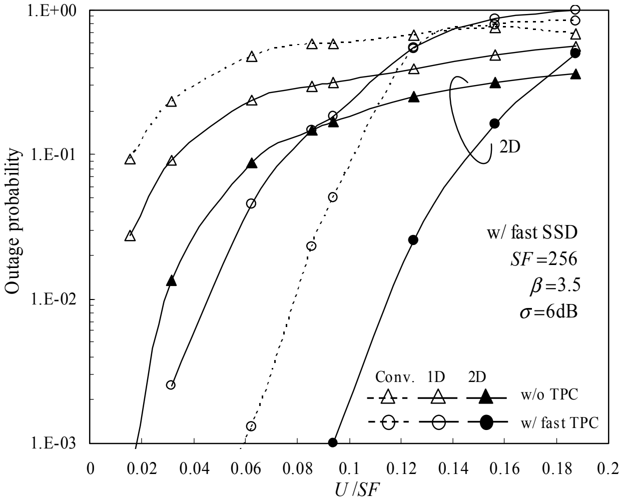

Fig. 6 Comparison between outage probabilities of conventional, 1D block spread and 2D block spread DS-CDMA.