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2次元ブロック拡散 DS-CDMA セリラシステムの上りリンク容量

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あらまし 2次元ブロック拡散 DS-CDMA は,周波数選択フェージングチャンネル環境下において上りリンク MAI(Multi-access interference)を避けつつ,マルチレート伝送が可能である.しかし,マルチセル環境では,セル間干渉が生じる.従来の DS-CDMA は,SSD (site selection diversity) を用いることで,セル間干渉を低減し,リンク容量を増加ことができた.しかし,遠近問題を解決するために,TPC (transmit power control) が必要である.本論文では,SSD および TPC を用いる2次元ブロック拡散 DS-CDMA の上りリンク容量をシミュレーションにより求める,従来の DS-CDMA との比較を行っている.

キーワード 2次元ブロック拡散,MAI,SSD,TPC,DS-CDMA 上りリンク.

Uplink Capacity of A Cellular 2-dimensional Block Spread DS-CDMA System

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Abstract 2-dimensional (2D) block spread direct sequence-code division multiple access (DS-CDMA) allows mutli-rate without causing uplink 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. Transmit power control (TPC) is necessary in order to solve the well-known 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 that of conventional.

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

1. INTRODUCTION

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 [1], [2] to remove MAI through simple block despreading. Block despreading converts an MUD problem into a set of equivalent single-user equalization problems [1], [2]. More recently, we have proposed 2-dimensional (2D) block spreading using orthogonal variable spreading factor (OVSF) codes [3] for quasi-synchronous uplink transmission [4]. 2D block spreading makes it possible to cancel the MAI as well as to make full use of time- and frequency-domain diversity. However, so far, only single-cell uplink environment was considered in [1], [2], [4]. 2D block spread DS-CDMA can only remove the intra-cell interference in a cellular system. The uplink with 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 [7]. The site selection diversity (SSD) can be used to reduce the inter-cell interference and increase the uplink capacity [5], [6]. SSD was proposed to reduce the inter-cell interference and increase the uplink capacity [6].

In this paper, we consider the impact of SSD and TPC on the uplink capacity of 2D block spread DS-CDMA in a cellular environment. We assume an interference-limited system, where the effect of background noise can be neglected compared with MAI. 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 transmission model of a cellular 2D block spread DS-CDMA using SSD and TPC. We derive an expression for the received signal-to-interference plus noise power ratio (SINR) in Sect. 3. Also we compare the uplink capacities of 2D block spread DS-CDMA, 1D block spread DS-CDMA and conventional DS-CDMA. Using the derived SINR, the outage probability is evaluated by a Monte-Carlo numerical computation method in Sect. 4. Sect. 5 offers conclusions.

2. UPLINK TRANSMISSION 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 give predominant interferences to the desired cell [7]. The BS is located at the center of each cell. An omni transmit antenna is assumed for all BS's. An uplink 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. In the uplink, different users' signals are code-multiplexed at the BS transmitter and then transmitted to MS'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.

2.1 2D block spread DS-CDMA

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 $(\cdot)^T$ denotes transpose. The $u(c)$th user's spread signal can be expressed using an equivalent baseband signal representation as

$$\hat{\mathbf{s}}_{u(c)}=\sqrt{2P_{T,u(c)}}\left[\tilde{\mathbf{x}}_{u(c)}(0),\cdots,\tilde{\mathbf{x}}_{u(c)}(SF^t_{u(c)}-1)\right]^T, \tag{3}$$

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

$$\begin{aligned}\tilde{\mathbf{x}}_{u(c)}(m)=c^{scr}_c(t;m)c^t_{u(c)}(m)[b_{u(c)}(N_c-N_g),\cdots,\\ b_{u(c)}(N_c-1),b_{u(c)}(0),\cdots,b_{u(c)}(N_c-1)]^T\end{aligned}, \tag{4}$$

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 guard interval (GI) length, long enough to avoid inter-block interference (IBI), and $b_{u(c)}(n)$ is given by

$$b_{u(c)}(n)=c^f_{u(c)}(n\,\mathrm{mod}SF^f_{u(c)})d_{u(c)}(\lfloor n/SF^f_{u(c)}\rfloor), \tag{5}$$

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 U users' faded signals in 18 cells is received by the 0th cell. The received signal vector $\mathbf{r}_0$ with length $SF^t_{0(0)}(N_c+N_g)$ can be represented as

$$\mathbf{r}_0=\sum_{c=0}^{18}\sum_{u=0}^{U-1}\sqrt{A_{u(c)\_0}}\tilde{\mathbf{H}}_{u(c)\_0}\hat{\mathbf{s}}_{u(c)}+\boldsymbol{\mu}, \tag{6}$$

where $\tilde{\mathbf{H}}_{u(c)\_c}$ 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 $A_{u(c)\_0}$ is given by

$$A_{u(c)\_0}=r^{-\beta}_{u(c)\_0}10^{-0.1\eta_{u(c)\_0}} \tag{7}$$

with $r_{u(c)\_0}$ being the distance between the 0th BS and the $u(c)$th MS, β the path loss exponent, and $\eta_{u(c)\_0}$ the lognormal shadowing loss with zero mean and variance $2\sigma^2$ [7].

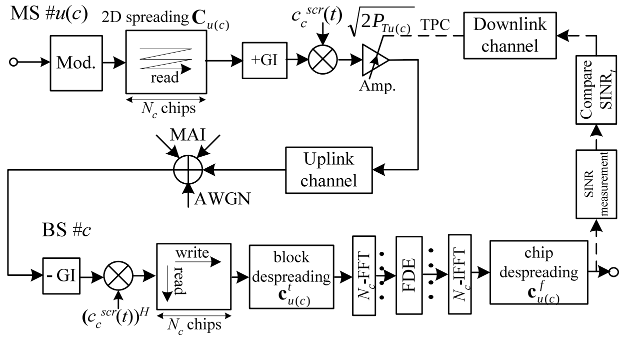

Fig. 1. Uplink transmission model.

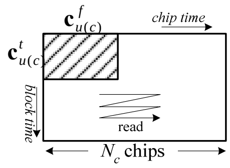

Fig. 2. 2D block spreading.

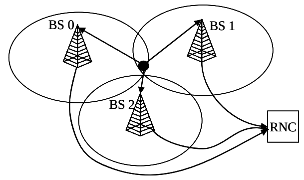

Fig. 3. Uplink SSD.

We assume an L-path block fading channel having an exponential power delay profile with path gains $\{h_{u(c)\_c,l}(t);\ l=0\sim L-1\}$, time delays $\{\tau_{u(c)\_c,l};\ l=0\sim L-1\}$ and the maximum Doppler frequency f_D. The block fading means that path gains $\{h_{u(c)\_c,l}\}$ 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 $h_{u(c)\_c,l}(m)$ and $E[|h_{u(c)\_c,l}(m)|^2]=(1-\alpha^{-1})/(1-\alpha^{-L})\alpha^{-l}$ ($E[\cdot]$ is the ensemble average operation). $\tau_{u(c)\_c,l}$ is assumed to be $\tau_{u(c)\_c',l}=\tau_{u(c)\_c}+l$, where $\tau_{u(c)\_c}$ is the $u(c)$th MS's timing offset and the maximum time delay is assumed to be shorter than the GI. $\tilde{\mathbf{H}}_{u(c)\_c}$ can be expressed as

$$\tilde{\mathbf{H}}_{u(c)\_c}=diag\left\{\mathbf{H}_{u(c)\_c}(0),\ldots,\mathbf{H}_{u(c)\_c}(SF^t_{u(c)}-1)\right\}, \tag{8}$$

where $\mathbf{H}_{u(c)\_c}(m)$ is the mth block $(N_c+N_g)\times(N_c+N_g)$ circulant Toeplitz channel matrix and its first column is given by [7]

$$\mathbf{h}_{u(c)\_c}(m)=[h_{u(c)\_c,0}(m),\ldots,h_{u(c)\_c,L-1}(m),\ldots,0]^T. \tag{9}$$

2.2 Site Selection Diversity

Assuming that all users transmit their pilot signals with equal power, each BS measures the local received signal power and sends it to radio network controller (RNC), as shown in Fig. 3. The RNC sorts them out in a descending order [6]. We consider two kinds of SSD: slow SSD and fast SSD.

For slow SSD, the BS's are ranked based on the measurement of $\{P_{T,0(0)}A_{0(0)\_c};c=0\sim C-1\}$. Without loss of generality, the BS index is given in a descending order. We assume that

$$P_{T,0(0)}A_{0(0)\_0}>\cdots>P_{T,0(0)}A_{0(0)\_(C-1)}>0. \tag{10}$$

For fast SSD, the BS's are ranked based on $\{P_{T,0(0)}A_{0(0)\_c}\sum_{l=0}^{L-1}\left|h_{0(0)\_c,l}\right|^2;c=0\sim C-1\}$. We assume that

$$P_{T,0(0)}A_{0(0)\_0}\sum_{l=0}^{L-1}\left|h_{0(0)\_0,l}\right|^2>\cdots>P_{T,0(0)}A_{0(0)\_(C-1)}\sum_{l=0}^{L-1}\left|h_{0(0)\_(C-1),l}\right|^2>0. \tag{11}$$

For both slow SSD and fast SSD, only the strongest BS is selected by radio network controller (RNC) to receive signal from the target user as shown in Fig. 3 [6].

2.3 Transmit Power Control

The power transmitted by each user experiences path loss, shadowing, and multipath fading within the wireless channel. The target of TPC is to let the received power be constant. Two power control mechanisms are considered: one is slow TPC, which regulates the distance dependent path loss and shadowing loss, and the other is fast TPC, which regulates the instantaneous power variation due to multipath fading as well as the distance-dependent path loss and shadowing loss. The fast TPC needs the feedback estimated channel quality $\{A_{u(c)\_c}\}$ and $\{h_{u(c)\_c,l}\}$ from MS's. In this paper, we assume the ideal feedback (no delay and error). Letting the TPC target be denoted by P_{target}, we have

$$P_{T,u(c)} = \begin{cases} P_{target} & \text{no TPC} \\ P_{target}\{A_{u(c)\_c}\}^{-1}, & \text{slow TPC} \\ P_{target}\left\{A_{u(c)\_c}\sum_{l=0}^{L-1}\left|h_{u(c)\_c,l}\right|^2\right\}^{-1}, & \text{fast TPC} \end{cases}. \quad (12)$$

2.4 Bit Error Rate

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 $\mathbf{c}_0^{scr}(t) = [c_0^{scr}(t;0),\ldots, c_0^{scr}(t;SF^t_{0(0)}-1)]^T$ and $\mathbf{c}^t_{0(0)}$ as

$$\hat{\mathbf{r}}_{0(0)} = \sum_{c=0}^{18}\sum_{u=0}^{U+\delta U_c-1}\sqrt{2P_{T,u(c)}A_{u(c)\_0}}\,\hat{\mathbf{H}}_{u(c)\_0}\mathbf{b}_{u(c)} + \hat{\boldsymbol{\mu}}, \quad (13)$$

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

$$\hat{\mathbf{H}}_{u(c)\_0} = \frac{1}{SF^t_{0(0)}}\sum_{m=0}^{SF^t_{0(0)}-1}\mathbf{H}_{u(c)\_0}(m) \times \left(c_0^{scr}(t;m)c^t_{0(0)}(m)\right)^* c_c^{scr}(t;m)c^t_{u(c)}(m). \quad (14)$$

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 $\{\mathbf{c}^t_{u(0)}; u = 0 \sim U-1\}$ are used, we have

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

where $\mathbf{0}_{N_c}$ is the $N_c \times N_c$ zero matrix. Therefore, the intra-cell interference is removed using simple block despreading [4].

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

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

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 $F_{x,y} = (1/\sqrt{N_c})\exp(-j2\pi xy/N_c)$, $\hat{\underline{\mathbf{W}}}_{0(0)\_0}$ is the $N_c \times N_c$ diagonal FDE weight matrix according to the minimum mean square error (MMSE) criterion, and $(\cdot)^H$ denotes Hermitian transpose. $\hat{\underline{\mathbf{W}}}_{0(0)\_0}$ is given by

$$\hat{\underline{\mathbf{W}}}_{0(0)\_0} = \frac{\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\left(\hat{\underline{\mathbf{H}}}_{0(0)\_0}\right)^H}{\left[\sum_{c=0}^{18}\sum_{u=0}^{U-1}2P_{T,u(c)}A_{u(c)\_0}\left\|\hat{\underline{\mathbf{H}}}_{u(c)\_0}\right\|^2 + \frac{2N_0}{SF^t_{0(0)}T_c}\mathbf{I}_{N_c}\right]} \quad (17)$$

with $\hat{\underline{\mathbf{H}}}_{u(c)\_0} = \mathbf{F}\hat{\mathbf{H}}_{u(c)\_0}\mathbf{F}^H$, where $\|\mathbf{A}\|^2 = \mathbf{A}^H\mathbf{A}$ is the norm of matrix $\mathbf{A}$, $(\cdot)^H$ denotes the Hermitian process and $\mathbf{I}_{N_c}$ is the $N_c \times N_c$ 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.

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. The signal-to-interference plus noise ratio (SINR) λ of 2D block spread DS-CDMA can be expressed as

$$\lambda = \frac{2\cdot S}{I_{SI} + I_{Intra} + I_{Inter} + I_{Noise}} \quad (18)$$

with

$$\begin{cases} S = \left(\overline{tr}\left(\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\,\hat{\underline{\mathbf{W}}}_{0(0)\_0}\hat{\underline{\mathbf{H}}}_{0(0)\_0}\right)\right)^2 \\ I_{SI} = \frac{1}{SF^f_{0(0)}}\left[\overline{tr}\left(\left\|\sqrt{2P_{T,0(0)}A_{0(0)\_0}}\,\hat{\underline{\mathbf{W}}}_{0(0)\_0}\hat{\underline{\mathbf{H}}}_{0(0)\_0}\right\|^2\right) - S\right] \\ I_{Intra} = \frac{1}{SF^f_{0(0)}}\sum_{u=1}^{U-1}\overline{tr}\left(\left\|\sqrt{2P_{T,u(0)}A_{u(0)\_0}}\,\hat{\underline{\mathbf{W}}}_{0(0)\_0}\hat{\underline{\mathbf{H}}}_{u(0)\_0}\right\|^2\right) \\ I_{Inter} = \frac{1}{SF^f_{0(0)}}\sum_{c=1}^{18}\sum_{u=0}^{U-1}\overline{tr}\left(\left\|\sqrt{2P_{T,u(c)}A_{u(c)\_0}}\,\hat{\underline{\mathbf{W}}}_{0(0)\_0}\hat{\underline{\mathbf{H}}}_{u(c)\_0}\right\|^2\right) \\ I_{Noise} = \frac{1}{SF^t_{0(0)}SF^f_{0(0)}}\frac{2N_0}{T_c}\overline{tr}\left(\left\|\hat{\underline{\mathbf{W}}}_{0(0)\_0}\right\|^2\right) \end{cases}, \quad (19)$$

where $\overline{tr}(\mathbf{A}) = (1/N_c)tr(\mathbf{A})$ is the normalized trace of an $N_c \times N_c$ matrix $\mathbf{A}$. Replacing Eq. (15) into Eq. (19), we have I_{Intra}=0 for 2D block spread DS-CDMA.

1-dimensional (1D) block spread DS-CDMA [1], [2] is a special case of 2D block spread DS-CDMA with $SF^t_{u(c)} \times SF^f_{u(c)} = SF_{u(c)} \times 1$. Although there is no intra-cell interference, the self interference and inter-cell interference cannot be reduced since $SF^f_{u(c)} = 1$. On the other hand, conventional DS-CDMA is another special case of 2D block spread DS-CDMA with $SF^t_{u(c)} \times SF^f_{u(c)} = 1 \times SF_{u(c)}$, where the intra-cell interference is remained and that approximate the interferences as zero-mean Guassian noise.

Assuming QPSK data-modulation, the conditional BER for the given sets of $\{\mathbf{H}_{u(c)\_0}; u=0\sim U-1, c=0\sim 18\}$ and $\{A_{u(c)\_0}; u=0\sim U-1, c=0\sim 18\}$ is given by [7]

$$P_b(\lambda) = 0.5erfc\sqrt{\lambda/4}, \quad (20)$$

where $erfc(\cdot)$ is the complementary error function. The average BER of uncoded DS-CDMA can be numerically evaluated by averaging Eq. (20) over all $\{\mathbf{H}_{u(c)\_0}\}$ and $\{A_{u(c)\_0}\}$.

3. NUMERICAL RESULTS

In this paper, we assume that each user has the same overall spreading factor of 2D OVSF spreading codes, $SF = 256$, to keep the same data rate. As for the 2D block spreading code assignment [4], we assign all users to use $SF^{t}_{u(c)} = U$ and by using orthogonal spreading sequences, all U users are orthogonal if $U<SF$ is satisfied. We calculate the average SINR of all U users per cell for 2D block spread DS-CDMA uplink.

Employing Monte Carlo numerical method, the uplink outage probability is evaluated. The local BER averaged over the multipath fading statistics is obtained for 2D block spread DS-CDMA with MMSE-FDE. 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 numerical simulation condition. It is assumed that the shadowing loss and the location of each MS remain invariant during communication (the user mobility is not considered). Also we assume an interference-limited system.

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 Rayleigh fading with uniform power delay profile
Required BER	$BER_{req}=10^{-2}$
Required outage probability	$Q_0=10^{-1}$

3.1. Impact of SSD on the outage probability of 2D block spread DS-CDMA

Fig. 4 compares the outage probability of 2D block spread DS-CDMA with different SSD schemes when 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. Especially, the joint use of fast SSD and fast TPC achieves the best performance. If the allowable outage probability is 0.1, the normalized uplink capacity, is around 0.15, which is 5 times that of 2D block spread DS-CDMA without SSD.

3.2. Outage probability comparison between of conventional, 1D block spread and 2D block spread DS-CDMA

Fig. 5 compares the outage probabilities of conventional, 1D block spread and 2D block spread DS-CDMA as a function of the normalized number of users when 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, but it is still remained in conventional DS-CDMA. Although 1D block spread DS-CDMA has no intra-cell interference, the self interference cannot be sufficiently reduced, resulting in much worse outage probability than 2D block spread DS-CDMA.

6. CONCLUSION

In this paper, we discussed the impact of site selection diversity (SSD) and transmit power control (TPC) on the uplink capacity of a 2D block spread DS-CDMA cellular system. We showed by numerical computer simulation that the joint use of TPC and SSD can significantly improve the uplink capacity of 2D block spread DS-CDMA. Since the intra-cell interference is removed, 2D block spread DS-CDMA achieves much better uplink capacity than conventional DS-CDMA. 2D block spread DS-CDMA with fast TPC and fast SSD gives the best uplink capacity irrespective of the channel frequency-selectivity.

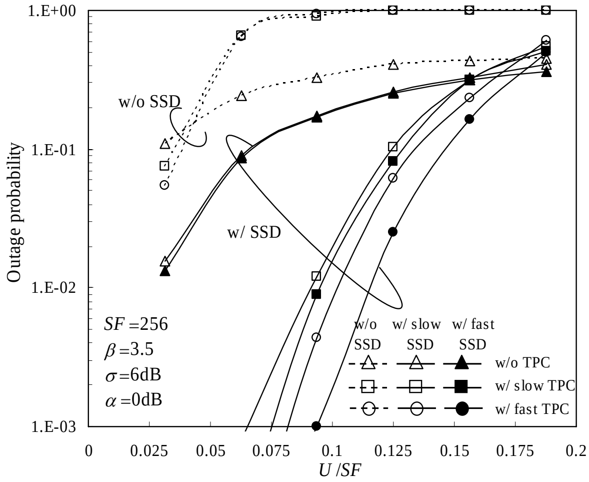

Fig. 4. Impact of SSD.

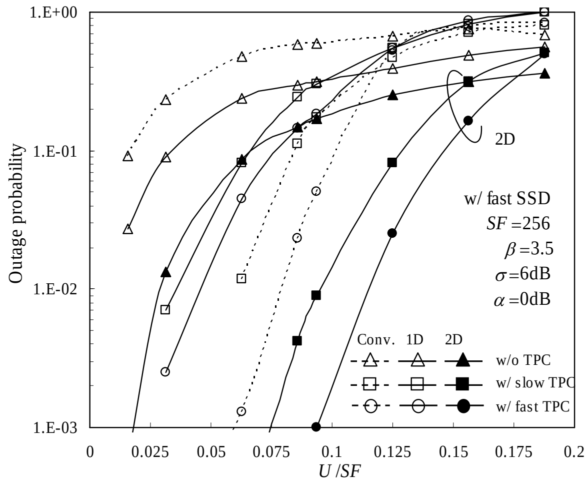

Fig. 5. Outage probability comparison.

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