A Code Assignment Algorithm for Multi-user/Multi-rate 2-Dimensional Block Spread SC-CDMA

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***Abstract*—2-dimensional (2D) block spread CDMA is able to achieve multiple-access interference (MAI) uplink transmission free in a slow fading channel. An important issue is how to efficiently assign the limited resource of spreading codes to users with different data rates to assure the requirement of quality of service (QoS). In this paper, a code assignment algorithm is proposed for the uplink 2D block spread SC-CDMA. Computer simulation is showed that the proposed code assignment algorithm achieves lower blocking probability than traditional CDMA.**

Keywords- 2D block spread CDMA, code assignment, code reuse efficiency.

I. INTRODUCTION

A flexible support of multi-rate broadband services is demanded for next generation mobile communications systems [1~2], which can be achieved by multi-code code division multiple access (multi-code CDMA) [2~4]. The use of frequency-domain equalization (FDE) based on the minimum mean square error (MMSE) criterion provides good bit error rate (BER) performance in a severe frequency-selective fading channel for CDMA system [5].

For the uplink (mobile-to-base station (BS)) transmission, since different users' signals are asynchronously received via different fading channels and therefore, the multiple access interference (MAI) occurs which limits the uplink capacity. The use of 2-dimensional (2D) block spread CDMA can be applied to solve the MAI problem [6]. In the two-dimensional spreading, chip-level spreading and block-level spreading are used. The chip-level spreading plays the same role as traditional SC-(or MC-) CDMA, which is used to achieve the frequency diversity gain; while the block-level spreading has an important role to remove the MAI. Both spreading codes can be constructed using the orthogonal variable spreading factor (OVSF) code tree [7].

The OVSF code has a unique property. The descendant and ancestor codes of the same root code cannot be used simultaneously because any two codes taken from the same mother code are not orthogonal to each other [7]. Therefore, the OVSF code tree has a limited number of available codes (limited code capacity). Many code assignment algorithms were proposed for CDMA [8~21]. However, even if the whole spreading codes constructed using OVSF code tree are successfully assigned to users, the received signal-to-interference plus noise power ratio (SINR) may sometimes drop due to fading. Therefore, not only the code blocking probability due to the code capacity limitation but also the BER performance needs to be considered.

To overcome the code limitation problem in a multi-cell environment, an efficient code reuse algorithm was proposed in [22] for 2D block spread cellular CDMA uplink. However, in that paper, the same data rate is assumed for all users. In this paper, we propose a code assignment algorithm for the uplink multi-user/multi-rate 2D block spread SC-CDMA.

The remainder of the paper is organized as follows. Section 2 briefly reviews some conceptions. The uplink transmission model is presented in Sect. 3. Then, the code reuse algorithm is proposed in Sect. 4. In Sect. 5, simulation results on the blocking probability are discussed. Sect. 6 offers some concluding remarks.

II. 2D CODE ASSIGNMENT AND BLOCKING

A. 2D code assignment

Figure 1 illustrates the OVSF code tree [7]. All codes in the same layer are orthogonal to each other; while codes in different layers are orthogonal only if they do not have the same mother code.

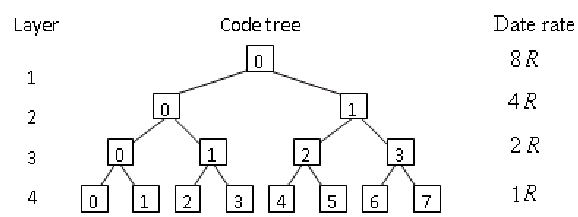

Figure 1. OVSF code tree.

To keep the orthogonality among different users, orthogonal codes taken from the OVSF tree can be used to realize the requested date rate.

The spreading factor for the lowest data rate R (in the highest layer) is denoted by $SF_{\max}$ ($SF_{\max} = SF_{f\max} \times SF_{t\max}$) in

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this paper. If the data rate of the u-th user is C_u times the lowest rate, the spreading factor of the u-th user with data rate R_u is given by

$$SF_u = \frac{SF_{\max}}{C_u} \quad . \tag{1}$$

B. Blocking probability

Users can be blocked because of the capacity limitation of the OVSF code tree; or the transmission quality of the users drop below the required QoS. In this paper, the transmission quality is represented by the BER. If the BER of user u becomes higher than the required BER_{req}, user u is declared to be blocked.

The blocking probability P_{block} is defined as

$$P_{block} = \frac{U_{block\_by\_CodeLimited} + U_{block\_by\_FaildedInQoS}}{U_{total\_come}} , \tag{2}$$

where $U_{block\_by\_CodeLimited}$ denotes a total number of users who could not be served due to the code capacity limitation, $U_{block\_by\_FaildedInQoS}$ denotes a total number of users whose link quality could not satisfy the required QoS, and U_{total_come} denotes a total number of arrival users over a measurement time interval.

III. UPLINK TRANSMISSION MODEL

Uplink signal transmission of the u-th user in the b-th cell is considered. The spreading factors of chip- and block-level spreading for the u-th user are denoted by $SF_{u,f}$ and $SF_{u,t}$, respectively, while the total spreading factor of the u-th user is SF_u $(= SF_{u,f} \times SF_{u,t})$. In this paper, $\lfloor a \rfloor$ denotes the smallest integer larger than a.

A. Transmission signal

The data sequence to be transmitted from the u-th user in the b-th cell is denoted by $\{d_{b\_u}(n); n = 0 \sim N_c / SF_{u,f} - 1\}$, where N_c is the block size of fast Fourier transform (FFT) at a receiver. The data symbol sequence to be transmitted is spread by chip-level spreading code $\{c_{b\_u}^{SF_{u,f}}(t); t = 0 \sim SF_{u,f} - 1\}$ with $\left|c_{b\_u}^{SF_{u,f}}(t)\right| = 1$ and multiplied by a sequence $\{c_{b\_u}^{scr}(t); t = 0 \sim N_c - 1\}$ to make the resultant signal white-noise like. The resultant SC-CDMA chip sequence $\{s_{b\_u}^{SC}(t); t = 0 \sim 2N_c - 1\}$ is expressed as

$$s_{b\_u}^{SC}(t) = c_{b\_u}^{scr}(t) \cdot d_{b\_u}\left(\lfloor t / SF_f \rfloor\right) c_{b\_u}^{SF_{u,f}}(t \bmod SF_{u,f}) . \tag{3}$$

In the block-level spreading, each N_c-chip block is repeated $SF_{u,t}$ times and each block is multiplied by a chip taken from an orthogonal block-level spreading code $c_{b\_u}^{SF_{u,t}}(t)$, which is used by the u-th user in the b-th cell. The equivalent lowpass representation can be expressed as

$$\hat{s}_{b\_u}(t) = \sqrt{2P_{b\_u}} \cdot s_{b\_u}^{SC}(t \bmod N_c) c_{b\_u}^{SF_{u,t}}(\lfloor t / N_c \rfloor) , \tag{4}$$

for $t = 0 \sim SF_{u,t} \times N_c - 1$, where P_{b_u} is the transmit power of the u-th user belonging to the b-th cell. After inserting an N_g-chip guard interval (GI) in every N_c-chip block, a sequence of N_c-chip blocks is transmitted over a frequency-selective fading channel.

B. Received signal

The GI inserted signal is transmitted over a frequency- and time-selective fading channel. Assuming a channel having chip-spaced L independent paths, its impulse response $h_{b\_u}(\tau)$ of the channel between the u-th user in the b-th cell and its corresponding BS is expressed as

$$h_{b\_u}(\tau) = \sum_{l=0}^{L-1} h_{b\_u,l} \delta(\tau - \tau_{b\_u,l}) , \tag{5}$$

where $h_{b\_u,l}$ and $\tau_{b\_u,l}$ are respectively the complex-valued path gain and time delay of the l-th path. In this paper, it is assumed that $h_{b\_u,l}$ stays unchanged during block interval $T = T_c\left(N_c + N_g\right)$, but it changes block by block, $\tau_{b\_u,l}$ is equal to $\tau_{b\_u,l} = \tau_{b\_u} + l \cdot T_c$ ($l = 0 \sim L-1$) with being the chip length, and τ_{b_u} is the transmit timing offset. The maximum time delay is assumed to be shorter than the GI.

A sum of users' faded signals is received at the b-th cell BS. The GI-removed received signal can be expressed as

$$r(t) = \sum_{b=0}^{B-1} \sum_{u=0}^{U_b-1} \sum_{l=0}^{L-1} h_{b\_u,l} \hat{s}_{b\_u}(t - \tau_{u,l}) + n(t) \quad , \tag{6}$$

for $t = 0 \sim N_c \cdot SF_{t,\max} - 1$, where $n(t)$ is the zero-mean complex-valued noise samples due to the additive white Gaussian noise (AWGN) with variance $2N_0/T_c$ (N_0 is the AWGN one-sided power spectrum density), B is the number of cells and U_b is the number of arriving users in a time interval of $SF_{t,\max}$ consecutive blocks in the b-th cell.

To recover the transmission SC-CDMA signal of the u-th user, block-level de-spreading is carried out. Since we are assuming a block fading (i.e., path gains stay almost constant over a time interval of $SF_{t,\max}$ consecutive blocks), we have

$$\begin{aligned} r_{b\_u}(t) = & \frac{1}{SF_{t,\max}} \sum_{i=0}^{SF_{t,\max}-1} \sum_{l=0}^{L-1} h_{b\_u,l} \hat{s}_{b\_u}(t + iN_c - \tau_{u,l}) \left\{c_{b\_u}^{SF_{u,t\max}}\right\}^* + \\ & \frac{1}{SF_{t,\max}} \sum_{i=0}^{SF_{t,\max}-1} \sum_{\substack{u'=0 \\ u' \neq u}}^{U_b-1} \sum_{l=0}^{L-1} h_{b\_u',l} \hat{s}_{b\_u'}(t + iN_c - \tau_{u',l}) \left\{c_{b\_u}^{SF_{u,t\max}}\right\}^* + \\ & \frac{1}{SF_{t,\max}} \sum_{i=0}^{SF_{t,\max}-1} \left\{ \sum_{\substack{b'=0 \\ b' \neq b}}^{B-1} \sum_{u'=0}^{U_{b'}-1} \sum_{l=0}^{L-1} h_{b'\_u',l} \hat{s}_{b'\_u'}(t + iN_c - \tau_{u',l}) \right\} \left\{c_{b\_u}^{SF_{u,t\max}}\right\}^* \\ & + \frac{1}{SF_{t,\max}} \sum_{i=0}^{SF_{t,\max}-1} n(t + iN_c) \left\{c_{b\_u}^{SF_{u,t\max}}\right\}^* \end{aligned} \tag{7}$$

The first, second, third, and fourth terms in Eq. (7) are the desired signal, MAI from other users in its own cell, MAI from other users in other cells, and noise, respectively.

Each user is assigned orthogonal block-level spreading code. It is assumed that the transmit timing difference among different users in the same cell is shorter than the GI length. Furthermore, it is assumed that the fading is slow enough and the path gains stay almost unchanged over at least $SF_{t,\max}$ consecutive blocks. Since the block-level spreading codes $\left\{c_{b\_u}^{SF_{u,t}}(t)\right\}$ are orthogonal to each other, we have $\frac{1}{SF_{t,\max}}\sum_{i=0}^{SF_{t,\max}-1}\left\{c_{b\_u'}^{SF_{u',t}}\right\}\cdot\left\{c_{b\_u}^{SF_{u,t\max}}\right\}^{*}=0\;(u\neq u')$ and therefore, the MAI from its own cell is zero. However, MAI from other cells cannot be zero due to insufficient number of block-level spreading codes.

After block-level de-spreading, the frequency-domain chip equalization (FDE) and chip-level de-spreading are carried out similar as the traditional CDMA.

IV. Proposed Code Assignment Algorithm

Here assume the available spreading codes have been assigned for each cell. And the proposed code assignment algorithm (from step 1 to step 6) is used to realize multi-rate transmission. If any block-level code cannot be assigned by the algorithm, it is declared that this user is blocked.

The 2D block code assignment algorithm to realize multi-rate transmission consists of the following 6 steps and is shown in Fig. 2. Here U_{serv} is number of users who can be served with its requested data rate C_u. Since the length of the orthogonal spreading codes is a power exponent of 2, $SF_{t\max}$ and $SF_{f\max}$ are also a power exponent of 2. So, $SF_{t\max}$ is set to $SF_{t\max}=2^{\lceil\log_2 m\rceil}$. Since $SF_{\max}=SF_{f\max}\times SF_{t\max}$, $SF_{f\max}=SF_{\max}/SF_{t\max}$. Both $SF_{t\max}$ and $SF_{f\max}$ are used.

Step1: rank the new users in the ascending order of data rate according to new users' requested date rates. Set the code counter N=0, the user counter u=0. N and u (with data rate C_uR) can not be larger than $SF_{t\max}$ and U_b, respectively.

Step2: check if $u > U_b$. If $u > U_b$, the code assignment is completed (all the users are successfully assigned different codes); else go to step3.

Step3: check if SF_{fmax} is equal to or larger than C_u which is the user's requested data rate. If SF_{fmax} is larger than C_u, go to step4, else go to step5.

Step4: set $SF_{u,f} = SF_{f\max}/C_u$, $SF_{u,t} = SF_{\mathrm{tmax}}$ (since SF_{fmax} is larger than C_u according to Step 3, the requested data rate can be achieved by changing the chip-level spreading factor). Set N=N+1. If $N > SF_{t\max}$, the remaining users are blocked and go to step6; else, choose a user u=u+1 and go to step2.

Step5: set $SF_{u,f} = 1$ and $SF_{u,t} = SF_{t\max}/(C_u/SF_{f\max})$ (in this case, changing the chip-level spreading factor cannot approach the requested data rate). Set N=N+$C_u/SF_{f\max}$and check if $N > SF_{t\max}$ (i.e., an enough number of codes do not exist in the code space and therefore, the u-th user cannot be assigned a code which can achieve its required data rate C_u). If $N > SF_{t\max}$, the u-th user is blocked and go to step6. Else, sufficient number of codes exist in the code space and therefore, the u-th user can be assigned a code to achieve its required data rate C_u. Then, choose a user u=u+1 and go to step2.

Step6: end of the code assignment.

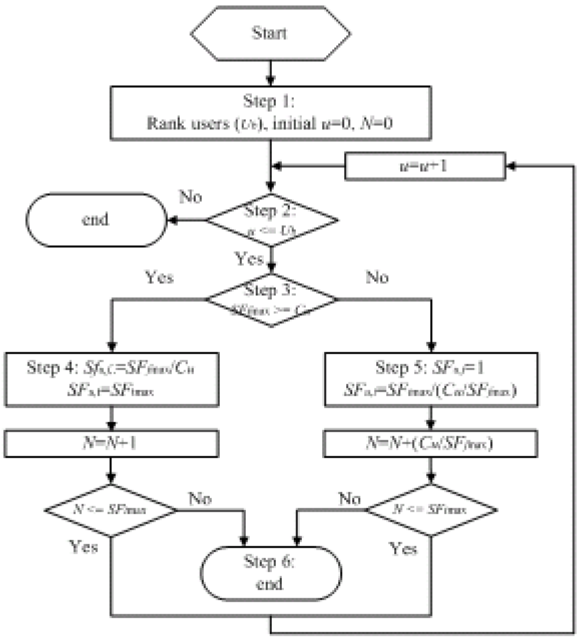

Figure 2. 2D block code assignment algorithm.

V. Computer Simulation

A. Simulation conditions

The performance of the proposed algorithm for 2D block spread SC-CDMA is evaluated by computer simulation. 6 neighboring cells surrounding the desired cell are considered. The simulation conditions are shown in Table 1. BS checks if the BER is lower than BER_{req}, it is declared that the user is successfully accessed, else the user is blocked.

The uplink channel is assumed to be a frequency-selective Rayleigh fading channel with a chip-spaced L=16-path uniform power delay profile and the normalized maximum Doppler frequency of $f_DT_c(N_c+N_g)$=0.001, where $f_D=\max_{b=0\sim6,u=0\sim U_b-1}\left(f_D^{b\_u}\right)$.

TABLE I. Simulation Conditions.

Transmitter	Modulation	QPSK
	Block length (number of FFT points)	$N_c = 256$
	GI	$N_g = 32$
	Spreading sequence	Walsh
	Spreading factor	$SF_{\max}$=128
Channel	Type of fading	Rayleigh
	Power delay profile	L=16-path uniform
	Maximum Doppler frequency	$f_D(N_c+N_g)T_c$=0.001
	Pass loss exponent	$\alpha = 4$
Receiver	Channel estimation	Ideal
	Equalization	MMSE-FDE

Users	Random arrival	Poisson distribution $\lambda = 1\sim16$
	Access time duration	1unit time
	User rates	R, $2R$, $4R$, $8R$

B. BER Performance

In 2D block spread CDMA, the achievable BER performance depends on the combination of ($SF_{u,f}$, $SF_{u,t}$, $SF_{t\max}$, U_b). $SF_{u,f}$ is the spreading factor of the chip-level spreading which obtains the frequency diversity gain. If $SF_{\max}$ and C_u are kept constant, the BER performance improves significantly by increasing $SF_{u,f}$ as shown in Fig. 3.

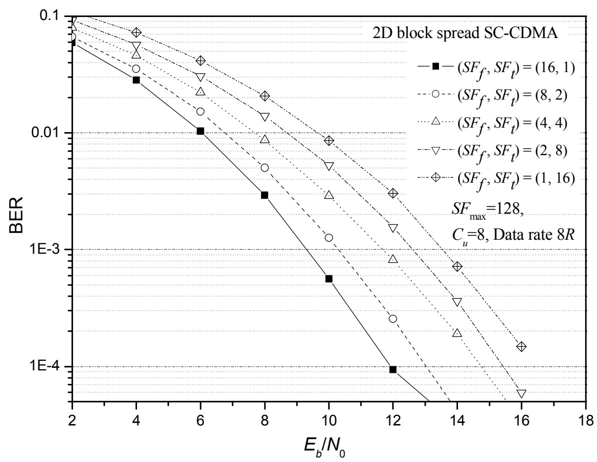

Figure 3. BER performance with the $SF_{\max}$ =128 and C_u=8.

If one of two spreading factors, $SF_{u,f}$ and $SF_{u,t}$, is kept constant while increasing the another spreading factor, the BER performance changes. By increasing $SF_{u,f}$ while keeping $SF_{u,t}$ constant, the BER performance improves significantly. On the other hand, when $SF_{u,f}$ is kept constant, the BER performance stays almost unchanged as shown in Fig. 4.

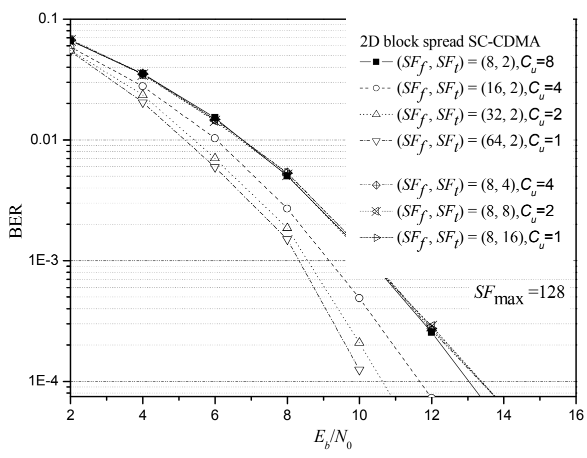

Figure 4. BER performance with different data rate as a parameter.

For 1D CDMA, the MAI limits the achievable BER performance. As the number of users increases, the BER performance degrades as shown in Fig.5, while 2D block spread CDMA provides a much better BER performance as shown in Fig. 6.

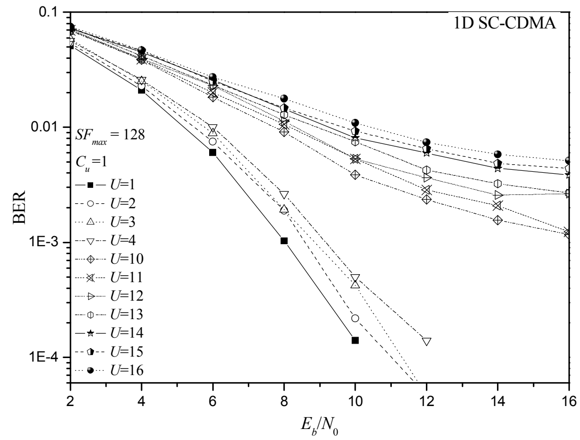

Figure 5. BER performance of 1D CDMA with the number of users as a parameter.

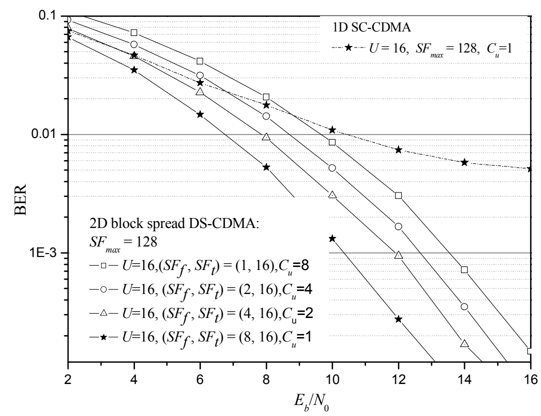

Figure 6. BER performance comparison between 2D block spread CDMA and 1D CDMA.

C. Blocking Probability

Assume BER_{req} is 0.01. The required BER influences the blocking probability greatly. The blocking happens more likely when the BER is very high. In Fig. 7, the blocking probability is compared between traditional 1D CDMA and 2D block spread CDMA. From the figure, it can be seen that the blocking probability of 2D block spread CDMA is much lower than that of 1D CDMA.

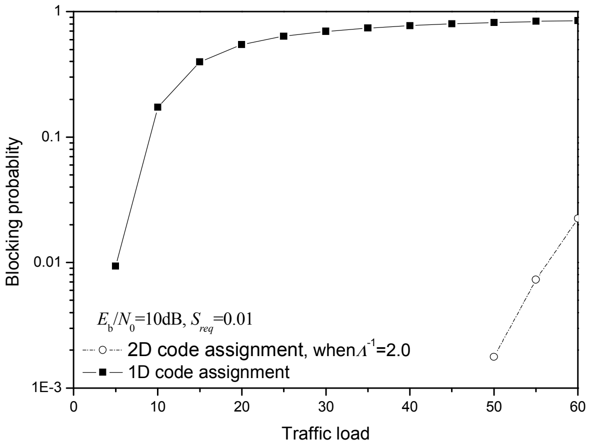

Figure 7. Blocking probability.

VI. CONCLUSIONS

This paper proposed a code assignment algorithm for uplink multi-user/multi-rate 2-dimensional (2D) block spread SC-CDMA system. We first presented a mathematic model and then described the algorithm in details. Computer simulation results demonstrated that the proposed code assignment algorithm can achieve higher code reuse efficiency while achieving a much better blocking probability performance.

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