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UPLINK CODE ASSIGNMENT ALGORITHM FOR A 2-DIMENSIONAL BLOCK SPREAD CDMA CELLULAR SYSTEM

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ABSTRACT

2-dimensional (2D) block spread CDMA achieves multiple-access interference (MAI) free uplink transmission while using low-complexity single-user detection. An important problem is how efficiently to assign the limited resource of spreading codes to users. In this paper, we propose a code assignment algorithm for the uplink of a 2D block spread CDMA cellular system. It is confirmed by the computer simulation that the proposed code assignment algorithm improves the code reuse efficiency.

I. INTRODUCTION

In cellular systems, the service area is covered by many cells and the same carrier frequency is reused in every cell to efficiently utilize the limited bandwidth. The code division multi-access (CDMA) allows the one-cell frequency reuse. There are two types of CDMA: direct sequence CDMA (DS-CDMA) and multicarrier CDMA (MC-CDMA). Both can be applied to cellular systems with single-cell frequency reuse. The 3rd generation (3G) systems based on wideband DS-CDMA with data rate of 384 kbps for continuous data transmissions and 14.4 Mbps for packet access have been deployed in many countries [1].

In the future cellular systems, broadband services with much higher data rates than 3G systems are demanded. The wireless channels for such broadband systems become very frequency-selective. Some advanced equalization techniques are necessary. Otherwise, the CDMA signal transmission performance becomes very poor. The use of frequency-domain equalization (FDE) based on the minimum mean square error (MMSE) criterion can significantly improve the bit error rate (BER) performance in a severe frequency-selective fading channel [2, 3].

However, for the uplink (from mobile-to-base) transmission, different users' signals are asynchronously received via different fading channels and therefore, the multiple access interference (MAI) occurs. The presence of MAI limits the uplink capacity. The use of 2-dimensional (2D) block spreading can be applied to solve the MAI problem [4].

The spreading code to be used in 2D block spread CDMA is a product of two spreading codes: the first-stage (chip-level) spreading code and second-stage (block-level) spreading code. The both spreading codes can be constructed using the orthogonal variable spreading factor (OVSF) code tree [5]. However, the number of orthogonal block-level spreading codes is limited. The same block-level spreading code must be reused in different cells. This produces the MAI from other cells and may reduce the link capacity.

The code reuse assignment of the block-level spreading codes is an interesting and important problem. Some code assignment algorithms have been proposed [6, 7]. But, these algorithms are at the expense of either signal-to-noise ratio (SNR) penalty or low code reuse efficiency. For example, the code reuse assignment algorithm in [7] must be under exact geometrical constraints which are hard in practical requirements.

This paper proposes an efficient code assignment algorithm to realize the efficient reuse of block-level spreading codes for the uplink of a 2D block spread CDMA cellular system. The remainder of the paper is organized as follows. Section 2 reviews 2D block spread CDMA. Then, the proposed code reuse assignment algorithm is presented in Sect. 3. In Sect. 4, the simulation results on the BER performance and on the code reuse efficiency are presented. Finally, Sect. 5 offers some concluding remarks.

II. 2D BLOCK SPREAD CELLULAR CDMA

A. Uplink Transmission

The transmitter/receiver structure of 2D block spread CDMA is shown in Fig. 1. 2D block spreading can be implemented by two-stage spreading. The first-stage (chip-level) spreading and the second-stage (block-level) spreading have different roles. The chip-level spreading is the same as traditional DS-(or MC-) CDMA and is used to obtain the frequency diversity gain, while the block-level spreading is used to remove the MAI. The spreading factors of chip- and block-level spreading are denoted by SF_f and SF_t, respectively.

First, the data symbol to be transmitted is spread using a chip-level spreading code. The resulting chip stream is divided into a sequence of N_c-chip blocks. In the case of MC-CDMA, N_c-point inverse fast Fourier Transform (IFFT) is applied to each N_c-chip block to generate an N_c-sample MC-CDMA signal block. In the second-stage spreading, each N_c-chip bock or N_c-sample MC-CDMA signal block is repeated SF_t times and each block is multiplied by a chip from an orthogonal block-level spreading code. Assuming a very slow fading channel, the MAI can be completely removed due to the orthogonal property of block-level spreading codes.

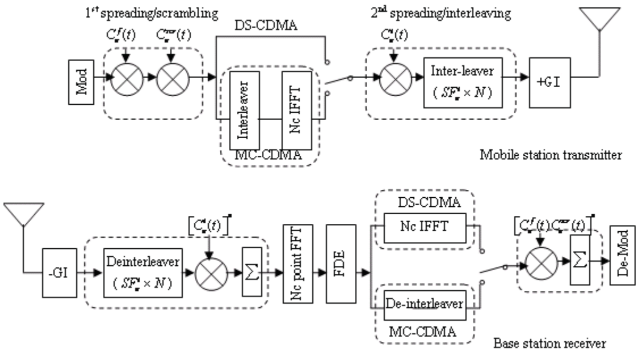
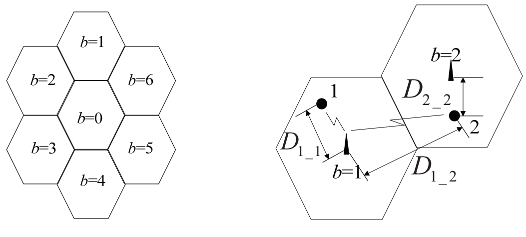


Figure 1: Uplink transmitter/receiver structure.

B. Interference Model

In CDMA system, users near the base station (BS) generate the strong MAI to the users far from the BS. So, transmit power control (TPC) is indispensible. With slow TPC, the average received signal power at the BS is always kept the same for all users. The users in the same cell are assigned different block-level spreading codes to avoid MAI. The same block-level spreading codes must be reused in different cells. In this paper, we consider a multi-cell environment consisting of 7 cells as shown in Fig. 2(a) (the center cell is a cell of interest and the others are an interfering cell).

The code reuse efficiency is defined as the average number of the same block-level spreading codes which can be reused in a cluster of 7 cells.



(a) 7-cell model (b) Interference model

Figure 2: Multi-cell model and interference model.

The transmit power of user u and its distance from BS are denoted by P_u and D_{b_u}, respectively, where b=0~6 as shown in Fig. 2(a). Assuming the perfect slow TPC and neglecting the shadowing, the average received signal at base station b is given as

$$P_u D_{b\_u}^{-\alpha} = P , \tag{1}$$

where P is the TPC target and α is the path loss exponent which is 2~4 in an urban area. The average received signal powers from all users in the same cell are kept as P.

The u-th user in the b-th cell is considered. By extending the analysis in [6] to the multi-cell case, the frequency-domain representation of the received signal for the u-th user in the b-th cell is given as

$$\begin{aligned} R_{b\_u}(k) &= P \cdot S_{b\_u}(k) H_{b\_u}(k) + P \sum_{\substack{u'=0 \\ u' \neq u}}^{U_b - 1} S_{b\_u'}(k) Z_{b\_u'}(k) \\ &+ P \cdot \left(\frac{D_{b'\_u'}}{D_{b\_u'}} \right)^{\alpha} \sum_{\substack{b'=0 \\ b' \neq b}}^{N_{cell}-1} \sum_{\substack{u'=0 \\ u' \neq u}}^{U_{b'}-1} S_{b'\_u'}(k) Z_{b'\_u'}(k) + \Pi_{b\_u}(k) \end{aligned} \tag{2}$$

where $S_{b\_u}(k)$ is the k-th frequency component of the u-th user transmit signal to the b-th BS, $R_{b\_u}(k)$, $\Pi_{b\_u}(k)$ and $H_{b\_u}(k)$ are the receive signal after block-level despreading, noise component and channel gain at the k-th frequency, respectively, and U_b is the total number of the users in the b-th cell. The second and third terms of (2) are the MAIs from other users in the own cell and in other cells, respectively. $Z_{b\_u'}(k)$ is the frequency-domain MAI after block-level despreading and is given by

$$Z_{b'\_u'}(k) = \frac{1}{SF_t^{b'\_u'}} \sum_{a=0}^{SF_t^{b'\_u'}-1} \left\{ \begin{aligned} & C_{b'\_u'}^{SF_t^{b'\_u'}}(i) \left\{ C_{b\_u}^{SF_t^{b\_u}}(i) \right\}^* \\ & \times \left[\sum_{l=0}^{L-1} h_{b\_u'\_l}(a) \exp\left(-j 2\pi k \frac{\tau_{b\_u'\_l}}{N_c} \right) \right] \end{aligned} \right\} \tag{3}$$

The fourth term of (2) is the zero-mean additive white Gaussian noise (AWGN).

Since $H_{b\_u}(k)$ $S_{b\_u}(k)$ and $Z_{b\_u}(k)$ are zero-mean complex Gaussian processes in Raleigh fading [6], the sum of the second, third, and fourth terms in (2) can be treated as a new zero-mean complex Gaussian variable with variance $2\sigma^2$ which is given by

$$\begin{aligned} 2\sigma^2 &= 2P^2 \sum_{\substack{u'=0 \\ u' \neq u}}^{U_n - 1} E\left[\left| Z_{b\_u'}(k) \right|^2 \right] \\ &+ 2P^2 \cdot \left(\frac{D_{b'\_u'}}{D_{b\_u'}} \right)^{2\alpha} \sum_{\substack{b'=0 \\ b' \neq b}}^{N_{cell}-1} \sum_{u'=0}^{U_n - 1} E\left[\left| Z_{b'\_u'}(k) \right|^2 \right] + 2\sigma_{AWGN}^2 \end{aligned} \tag{4}$$

where the first and second terms represent the variances of the MAI from the own cell and from the other cells, respectively, and E[.] denotes the ensemble average operation. $2\sigma_{AWGN}^2$ is the variance of

AWGN. $E\left[\left|Z_{b'\_u'}(k)\right|^2\right]$ is given as

$$E\left[\left|Z_{b'\_u'}(k)\right|^2\right]=\frac{1}{\left(SF_t^{b\_u}\right)^2}\sum_{a'=0}^{SF_t^{b\_u}-1}\sum_{a'=0}^{SF_t^{b\_u}-1}\left\{J_0\left(2\pi|a-a'|f_D^{b'\_u'}T\right)\right.$$
$$\left.\times\left[C_{b'\_u'}^{SF_t^{b'\_u'}}(a)C_{b\_u}^{SF_t^{b\_u}}(a')\left\{C_{b'\_u'}^{SF_t^{b'\_u'}}(a')C_{b\_u}^{SF_t^{b\_u}}(a)\right\}^*\right]\right\}, \quad (5)$$

where $C_{b\_u}^{SF_t^{b\_u}}(t)$ is the block-level spreading code used by the u-th user in the b-th cell, $f_D^{b\_u'}$ is the maximum Doppler frequency of the u'-th user in the b-th cell, and $J_0(.)$ is the zero-th order Bessel function of the first kind.

Below the code assignment is proposed for 2D block spread CDMA. If $f_D^{b\_u'}$=0, the value of the first term of (4) becomes zero since block-level spreading codes are orthogonal to each other. This means that the MAI from other users in the own cell can be completely removed. However, the number of codes is limited, the same block-level spreading code must be reused in different cells and therefore, the MAI is produced from users in other cells.

We introduce the distance ratio $\Lambda=D_{b'\_u'}/D_{b\_u'}$ ($0<\Lambda\le 1$). If Λ is small enough, the variance $2\left(\sigma_{i,j}^{other}\right)^2$ is negligibly small and the BER becomes small enough. Define Λ_0 as the largest allowable value of Λ as

$$\Lambda_0=\max_{\{QoS\}}\left(\frac{D_{b'\_u'}}{D_{b\_u'}}\right), \quad (6)$$

while satisfying the required quality of services (QoS). If $\Lambda<\Lambda_0$, the same spreading code can be reused. As Λ reduces, the fourth term of (4) becomes weaker. When $D_{b'\_u'}=0$, the MAI is completely removed even if the u'-th user in the b'-th cell can be assigned the same block-level spreading code as the u-th user in the b-th cell.

In order to find the boundary of the areas where the same spreading code can be reused, we consider two adjacent cells as shown in Fig. 3. The positions of the b-th BS and the b'-th BS are $(-a,0)$ and $(a,0)$, respectively. The u'-th user position (x, y) must satisfy the following condition

$$\frac{(x-a)^2+y^2}{(x+a)^2+y^2}\le\Lambda^2. \quad (7)$$

Assuming $\Lambda\ne 1$, (6) becomes

$$[x-\frac{1+\Lambda^2}{1-\Lambda^2}a]^2+y^2\le\left(\frac{2a\cdot\Lambda}{1-\Lambda^2}\right)^2. \quad (8)$$

The possible boundary is a circle with its centre O' and radius r, as shown in Fig. 3. O' and r are respectively given as $O'=\left(\frac{1+\Lambda^2}{1-\Lambda^2}a,0\right)$ and $r=\frac{2a}{1/\Lambda-\Lambda}$.

Note that r increases as Λ ($0<\Lambda<1$) increases. This means that when the required QoS is low, the corresponding Λ is large and therefore, the interfering u'-th user can be assigned the same spreading code.

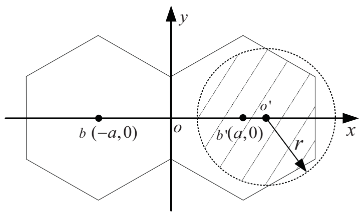


Figure 3: The boundary of the area where the same spreading code can be reused.

The same spreading code can be assigned to different users in different cells if the following conditions simultaneously are satisfied.

$$\begin{cases}\dfrac{D_{b'\_u'}}{D_{b\_u'}}\le\Lambda_0\\ \dfrac{D_{b\_u}}{D_{b'\_u}}\le\Lambda_0\end{cases}, \quad (9)$$

where $u'=0\sim U_{b'}-1$ ($u'\ne u$) and $b'=0\sim N_{cell}-1$ ($b'\ne b$).

III. Proposed Code Assignment Algorithm

A cluster of 7 cells is considered as in Sect. II. BS b=0 is a BS of a cell of interest and other BSs b=1~6 are an interfering BS. We assume that the perfect information of all users' locations is available. The proposed code reuse assignment algorithm is shown in Fig. 4, where m denotes the spreading code index in the block-level spreading code set.

Step 1: For the new arriving user, choose one code which is not in use by BS b=0 and has not been checked yet.
Step 2: Check if the chosen code is already in use by one of 6 neighbor BSs ($b=1\sim 6$). If yes, go to step 3; otherwise, go to step 1.
Step 3: Check if two users of BS b=0 and a neighboring BS $b\neq 0$ satisfy (8). If yes, assign the chosen code to the new arriving user. If not, go to step 1 again and choose the next code.

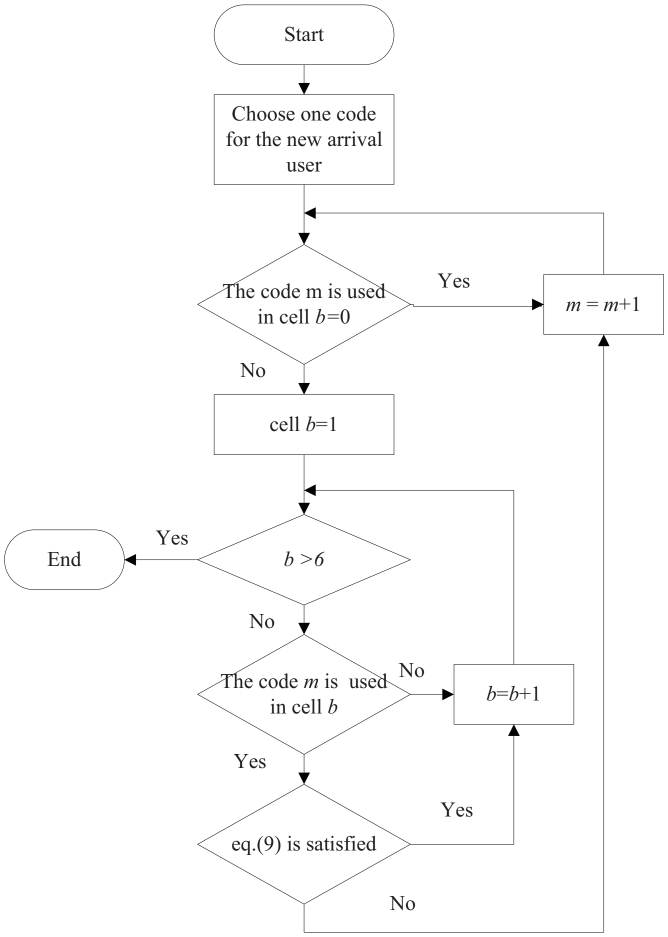


Figure 4: Proposed code reuse assignment algorithm.

IV. Performance Evaluation

The performance of the proposed code reuse assignment is evaluated by computer simulation for 2D block spread DS-CDMA with MMSE-FDE. 6 neighbor cells immediately surrounding the desired cell are considered. The simulation condition is shown in Table 1. The new users arrive in each cell following a Poisson process with average number λ of arrival users. The uplink channel is assumed to be a frequency-selective Rayleigh fading channel with a chip-spaced L=16-path uniform power delay profile (i.e., the l-th path delay time is l times the chip duration T_c) and the normalized maximum Doppler frequency of $f_D T_c N_c$=0.001.

Table 1: Simulation condition.

Transmitter	Modulation	QPSK
	Block length (number of FFT points)	N_c = 128
	GI	N_g = 32
	Spreading sequence	Walsh
	2D block Spreading factors	$SF_f \cdot SF_t = 128$
Channel	Type of fading	Rayleigh
	Power delay profile	L=16-path uniform
	Maximum Doppler frequency	$f_D N_c T_c$=0.001
	Pass loss exponent	α =4
Receiver	Channel estimation	Ideal
	Equalization	MMSE-FDE
Traffic	No. of users	Poisson distribution λ= 1~16
	Access time duration	1 unit time

A. *Minimum Required Distance Ratio*

First, the relationship between the BER performance and the distance ratio Λ^{-1} is discussed (Λ^{-1} is used instead of Λ). The simulation result is plotted with the block-level spreading factor SF_t as a parameter in Fig. 5, where E_b/N_0 is the average bit energy-to-AWGN power spectrum density ratio. Define U_{same} is the number of users who are assigned the same block-level spreading code in different cells ($U_{same} \leq 7$ for a 7-cell model). It can be seen from the figure that as Λ^{-1} increases, the MAI from other users in the other cells who are assigned the same block-level spreading code becomes weaker. When Λ^{-1} becomes large enough, the MAI can be negligibly small and therefore, almost the same BER performance can be achieved as the single user case. It is also seen that as the SF_f increases, the BER performance improves significantly; when U_{same}=1, the average BER becomes 5.2×10^{-3} when SF_f=1 and it becomes 2.1×10^{-4} when SF_f=16. The BER difference between different values of U_{same} is very small; assuming SF_f=1 and $\Lambda^{-1}=1.88$, the BER is =7.17×10^{-3} when U_{same} =7, while it is 7.06×10^{-3} when U_{same} =2.

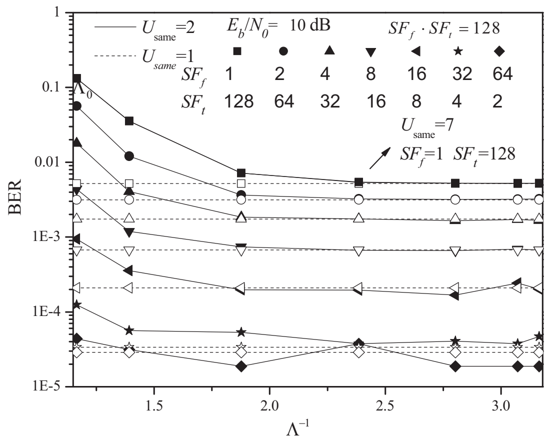


Figure 5: BER versus Λ^{-1} with SF_t as a parameter for SF_f=16 and E_b/N_0=10 dB.

B. Code Reuse Efficiency

The relationship between code reuse efficiency and traffic load is plotted in Fig. 6. Traffic load is defined as the average number of new user arrivals per cell times the call duration time. It is seen from Fig. 6 that the proposed code reused assignment algorithm achieves higher code reuse efficiency than the traditional one (which does not consider the code reuse) [4]. The code reuse efficiency improves as the traffic load increases. This is because as the traffic load increases, more number of users try to access the system, so the probability of users who are located in the code reuse area (indicated as circle area in Fig.3) increases. Furthermore, decreasing the value of Λ^{-1} can improve the code reuse efficiency at the expense of increased BER (the BER becomes larger than 1×10^{-3} when $\Lambda^{-1}>1.56$).

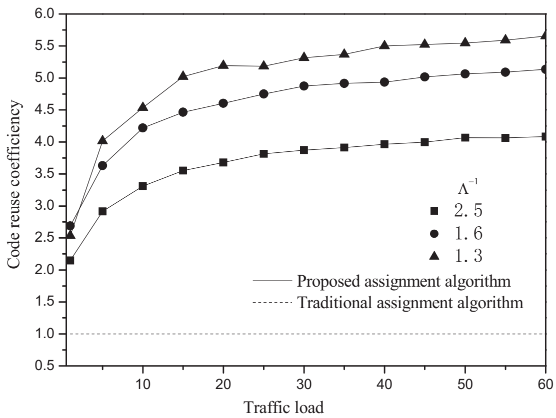


Figure 6: Code reuse efficiency versus traffic load.

V. Conclusion

This paper proposed a code reuse assignment algorithm for the uplink of a 2-dimensional (2D) block spread CDMA cellular system. The proposed algorithm assigns the same block-level spreading code to any pair of two users in different cells and thus can improve the utilization of the limited number of available codes. The proposed algorithm requires the knowledge of location information of users. The required condition on user locations to share the same code was presented. It was demonstrated that the proposed code reuse assignment algorithm can achieve higher code reuse efficiency compared to the traditional algorithm.

Acknowledgments

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