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Adaptive Code Assignment Algorithm for A Multi-user/Multi-rate CDMA System

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Abstract In this paper, we present a new adaptive code assignment algorithm. It has three main steps: reserved-space step, improved-crowed-first-space step, and multicode combination step. Compared with the existing algorithms, the proposed algorithm provides lower total blocking while its computational complexity is also comparatively low. It is applicable to all combinations users rate ratio probability. As a result, the proposed algorithm can be used in a multi-user/multi-rate CDMA system.

Keyword code assignment, CDMA, DCA, code tree, cost function

1. Introduction

In next generation mobile communications, a flexible support of multi-rate for multimedia services is required [1], [2]. Code division multiple access (CDMA) technique is used widely to solve this problem through changing the orthogonal spreading codes. The well-known CDMA techniques include single-carrier direct sequence DS-CDMA [2], [3] using time-domain spreading and multi-carrier MC-CDMA using frequency-domain spreading. Recently, the frequency-domain equalization (FDE) based on the minimum mean square error (MMSE) criterion has significantly improved the BER performance in a severe frequency-selective fading channel [2][4].

How to deal with the code assignment for multi-rate multi-user transmission is a serious problem. As is known, in OVSF CDMA, higher data rates are provided by using lower spreading factor. When a code is used in the OVSF code tree, its descendant and ancestor codes cannot be used [6]. This is because any two codes belonging to the same mother code are not orthogonal to each other. Therefore, the OVSF code tree has a limited number of available codes [7]. Since the maximum number of OVSF codes is limited, the efficient assignment of OVSF codes has a significant impact on the resource utilization. When old users leave and a new user arrives, the reassignment of OVSF codes should be efficiently done.

Recently, many researchers have been focusing on the code reassignment problem. In[8]~[12], various code assignment algorithms, such as random, leftmost, crowded -first-space, crowded-first-code, non-rearrangeable compact assignment(NCA)algorithms, have been proposed to find an optimum code to be assigned to a new comer. However, code-reassignment was not considered. In [13], [14], a dynamic code assignment (DCA) to reduce the blocking probability is presented, which is optimal in the sense that the number of OVSF codes that must be reassigned to support a new user, is minimized. However, these algorithms are very computationally complex [13]. Recently, less complex algorithms were proposed [15], [16]. These algorithms are a kind of static code assignment algorithm. But they are not very flexible compared with DCA and provide a relative high blocking probability since it does not consider the rate distribution. An interesting code assignment algorithm is a hybrid algorithm that combines a DCA algorithm with a static algorithm [17]~[19]. However, the hybrid algorithms in [17]~[19] do not consider the dynamic and static code space boundary clearly.

This paper focuses on the hybrid code assignment algorithm for a multi-rate/multi-user CDMA system. The remainder of the paper is organized as follows. Section 2 reviews the OVSF code tree and multi-code spreading. Then the paper will introduce the adaptive code assignment algorithm in Sect. 3. In Sect. 4, the simulation results for the blocking probability will be presented and discussed. Finally, Section 5 offers some concluding remarks.

2. Preliminary

2.1. OVSF code tree

OVSF codes can be represented by a code tree as shown in Fig.1.

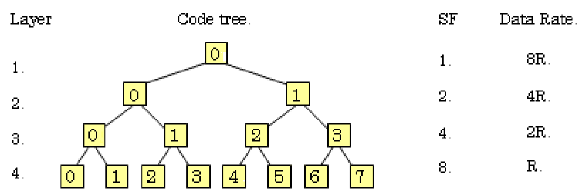


Fig.1 OVSF code tree.

Each OVSF code is denoted as $C_{p,k}$, where p represents the code layer of Walsh spreading codes and k $(0,1,\ldots\ldots,2^{p-1}-1)$ represents the index of spreading code in layer p. The root code is $C_{1,0}=(1)$ and the second layer has two codes, $C_{2,0}=(1,1)$ and, $C_{2,1}=(1,-1)$. The codes at the pth layer are generated as (C,C) and $(C,\overline{C})$ from each code C of the $(p-1)$th layer, where $\overline{C}$ is the bit-wise complement of C[8]. The number of codes available at each layer is determined by the spreading factor SF of the layer. All codes in the same layer are orthogonal while codes in different layers are orthogonal only if they do not have the same mother code. The data rate in the highest layer has the lowest rate *R*.

2.2. Blocking

A. Code Blocking

As explained earlier, code blocking is the major drawback of OVSF-CDMA system. Define code blocking probability as the probability when a new call is blocked even if the system has enough capacity to handle it. Fig. 2 shows the code tree with three codes used, seven codes are blocked they cannot be used and only five codes are free. Although the maximum capacity of Fig.2 is 8*R* and unused capacity is 4*R*, it can not offer a user with rate 4*R*. If this happens, this is called code blocking.

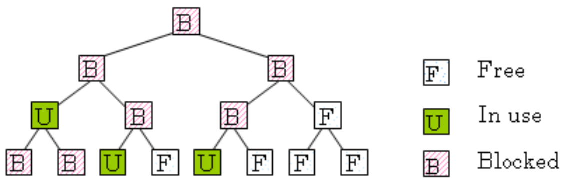


Fig.2 Code blocking.

B. Total blocking

The users arrive randomly according to Poisson distribution. Some users cannot be served because of the code limitation or capacity limitation. Even though there remain free codes, code blocking problem may occur due to the limited ability of code assignment algorithm. The total blocking is determined by both the code assignment algorithm and the number of arrival users.

C. Cost function

The cost function of code reassignment algorithm is important to evaluate the algorithm. In [13], the cost of reassigning an occupied code*C* is defined as the minimum number of code reassignments necessary to assign C to some other branch so that C and all descendant codes of C are left vacant. Since the reassignment of a leaf code of rate R results in no additional code reassignments its cost is 1 by definition. The actual cost depends on the number of reserved branches in the code tree. When there is an immediate vacancy in another branch, the cost is only 1. The cost of a branch is defined as the minimum number of code reassignments necessary to reassign all occupied codes in the branch to other branches so that the branch is left empty.

2.3. Multi-rate Transmission

To realize multi-rates transmission, basically there are two methods: multi-code transmission and two dimensional code transmission. Here introduce code multiplexing only.

Code-multiplexing provides a flexible rate transmission by using low rate orthogonal codes in parallel to achieve a higher rate transmission s shown in Fig. 3.

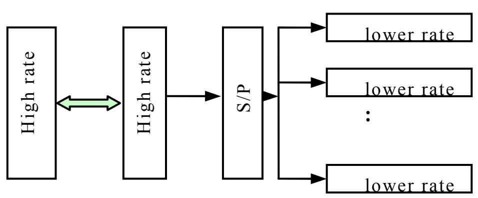


Fig.3 Code-multiplexing.

Assume that the coming user's rate is 8*R* and SF_{total} = 16. We need to use a code of *SF*=2 to realize the rate-8*R* transmission. Using code-multiplexing, possible code combinations are (4R, 4R), (4R, 2R, 2R), (4R, 2R, R, R), (4R, R, R, R, R), (2R, 2R, 2R, 2R), (2R, 2R, 2R, R, R), (2R, 2R, R, R, R, R), (2R, R, R, R, R, R, R), and (R, R, R, R, R, R, R, R). All of these code combinations give the same sum rate of 8*R.* The code-multiplexing is shown in Fig.4.

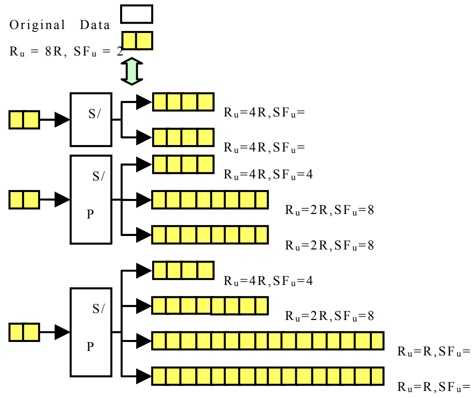


Fig.4 Code combinations.

3. Adaptive Code Assignment (ACA) Algorithm

In order to reduce the code blocking problem, we propose a new adaptive code assignment (ACA) algorithm. The proposed algorithm consists of three steps: reserved space (RS) step, improved crowed-first-space (ICFS) step, and multi-code combination (MCC) step.

3.1. Steps of ACA algorithm

Before describing RS, ICFS, and MCC in detail, overall algorithm is briefly presented below.

(1) The whole code space is divided into reserved code space and free code space. The capacity ratio of free code space to whole code space is denoted by *Q*, which is determined by the user data rate distribution.

(2) Rank the coming users in the ascending order of rate (low- to–high) according to users' requested rates.

(3) Assign a code to each user in RS step. If a code which has the requested rate by a user remains in the reserved space, assign this code to that user. Repeat this step for other users. If all users are assigned codes successfully, the code assignment procedure stops at this step. Otherwise, go to step (4) for users who have not been successfully codes yet.

(4) Check the available capacity of the free-space. If an enough capacity remains, carry out the code assignment using ICFS until all users have been code-assigned successfully. If not, go to step (5).

(5) Code-assign the remaining users using MCC step. In this step, if its remaining capacity of the free space is larger than or equal to the requested sum capacity, users can be code-assigned successfully. If not, some users will be refused, resulting in blocking.

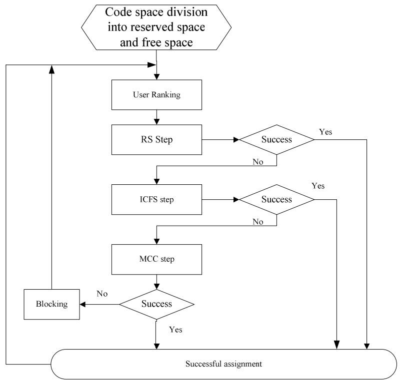


Fig.5 ACA algorithm.

3.2. Reserved-space step (RS)

R is the data rate supported by a leaf code. The code tree consists of C_{SF} leaves. In a code-limited single-cell case, the maximum system capacity is equal to C_{SF}. Since all codes are mutually orthogonal, there is no multiple access interference [13]. Thus, if the total number of users in the system is denoted by L and the rate of user $i$is denoted by k_iR, the following should be satisfied.

$$\sum_{i=1}^{L} k_i \le C_{SF} \tag{1}$$

The code assignment is based on Eq. (1). Divide the whole space into two: the reserved space and free space. Denote the rate distribution of (8R, 4R, 2R, R) by (P_{8R}, P_{4R}, P_{2R}, P_R) with

$$P_{8R} + P_{4R} + P_{2R} + P_R = 1 \tag{2}$$

Create a reserved space of (1-Q) times total capacity (0≤Q≤1).

The number N of supportable users in the reserved space is given by

$$N = \left\lfloor \frac{C_{SF} \times (1-Q)}{P_{8R} \times 8 + P_{4R} \times 4 + P_{2R} \times 2 + P_R \times 1} + 0.5 \right\rfloor \tag{3}$$

Therefore, the distribution of supportable users of different rates is given by

$$\begin{cases} N_{8R} = \lfloor NP_{8R} + 0.5 \rfloor \\ N_{4R} = \lfloor NP_{4R} + 0.5 \rfloor \\ N_{2R} = \lfloor NP_{2R} + 0.5 \rfloor \\ N_R = \lfloor NP_R + 0.5 \rfloor \end{cases} \tag{4}$$

The reserved space capacity is given by

$$C_{RS} = N_{8R} \times 8 + N_{4R} \times 4 + N_{2R} \times 2 + N_R \times 1 \approx C_{SF} \times (1-Q) \tag{5}$$

The free space capacity is given by

$$C_{FS} = C_{SF} - C_{RS} \approx C_{SF} \times Q \tag{6}$$

Below an example is given to show how the reserved space is created. Assume C_{SF}=32 and the user rate distribution of (8R, 4R, 2R, R)=(0.25, 0.25,0.25,0.25). When Q=0.5, we have

$$\begin{aligned} N &= \left\lfloor \frac{32 \times (1-Q)}{0.25 \times 8 + 0.25 \times 4 + 0.25 \times 2 + 0.25 \times 1} + 0.5 \right\rfloor \\ &= \left\lfloor \frac{32 \times (1-0.5)}{3.75} + 0.5 \right\rfloor = 4 \end{aligned} \tag{7}$$

$$\begin{cases} N_{8R} = \lfloor NP_{8R} + 0.5 \rfloor = \lfloor 4 \times 0.25 + 0.5 \rfloor = 1 \\ N_{4R} = \lfloor NP_{4R} + 0.5 \rfloor = \lfloor 4 \times 0.25 + 0.5 \rfloor = 1 \\ N_{2R} = \lfloor NP_{2R} + 0.5 \rfloor = \lfloor 4 \times 0.25 + 0.5 \rfloor = 1 \\ N_R = \lfloor NP_R + 0.5 \rfloor = \lfloor 4 \times 0.25 + 0.5 \rfloor = 1 \end{cases} \tag{8}$$

$$\begin{cases} C_{RS} = N_{8R} \times 8 + N_{4R} \times 4 + N_{2R} \times 2 + N_R \times 1 = 15 \\ C_{FS} = C_{SF} - C_{RS} = 32 - 15 = 17 \end{cases} \tag{9}$$

The resultant code distribution in each layer is shown in Table1.

Table 1 Code distribution

Layer	Reserved Space	Free Space
2, rate=8R	0	1~3
3, rate=4R	2	3~7
4, rate=2R	6	7~15
5, rate=R	14	15~31

Fig.6 shows this example. Black color represents the reserved code place, and white color means forbid place; grey color stands for the free space.

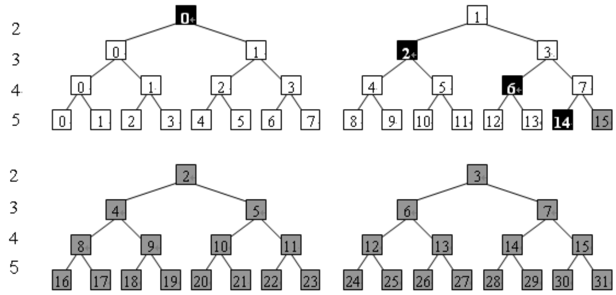


Fig.6 Code distribution space.

3.3. Improved-Crowed-First-Space (ICFS) Step

In the reserved space, we only need to find an appropriate coed according to each user's rate. Unlike the RS step, however, the ICFS step ranks the incoming users in the ascending (from low to high) order of rate. A lower rate user assigned a code first since the number of lower rate codes is larger and consequently to reduce the total blocking probability. This is the difference of the ICFS from the original crowed-first-space [8] algorithm. The ICFS step is described below.

(a) Check if the free-space has enough capacity. If so, go to (b), otherwise go to MCC step.

(b) Pick the candidate code whose ancestor code has the least free capacity. Compare the free capacities of their ancestors. The one with less free capacity (i.e., more crowded) will be chosen for use. If two ancestors have the same free capacity, follow the leftmost strategy to pick the code on the left-hand side.

3.4. Multi-Codes Combination (MCC) Step

After carrying out the RS step and ICFS step, if some users with higher rate still do not have been assigned a code, this step is used.

If the system has enough remaining capacity to accommodate a user, then assign the multiple codes according to the multi-code combination. The reason for carrying out the MCC step last is that the multi-code transmission increases the peak-to-average power ratio (PAPR) of the transmit signal and a linear power amplifier with wide dynamic range is required and this is a problem for implementing low cost mobile terminals.

So far, we have described the proposed ACA algorithm.

4. Simulation results

A computer simulator will be implemented to evaluate the performance of the proposed algorithm. The maximum SF is set to 128. New calls arrive in a Poisson process with lambda value from 1 to 16, and the rates are R, 2R, 4R, 8R which rates ratio shown as Table 2. Call duration time is exponentially distributed with a mean of 3 time units. Traffic load decided by the coming users' number and their packet duration time.

Table 2 Simulation conditions

Maximum SF	128
Users Distribution	Poisson Distribution, Lambda = 1~16
User rates	R, 2R, 4R, 8R
Rates ratio (8R:4R:2R:R)	0.1:0.4:0.4:0.1 0.25:0.25:0.25:0.25 0.1:0.1:0.4:0.4 0.4:0.1:0.1:0.4
Duration	Exponential distribution. Mean= 3.

4.1. Compare with other algorithms

4.1.1 Comparison of blocking probabilities

First, the code blocking probability of the proposed ACA algorithm is compared with other algorithms as shown in Fig. 7. It can be observed that given the condition that when the system capacity can afford the traffic load (when the traffic load is lower than the available capacity), code blocking with not happen when using ACA or DCA algorithms. However, code blocking happens to Random algorithm and Crowed-first space algorithm with increasing probability when the traffic load increases.

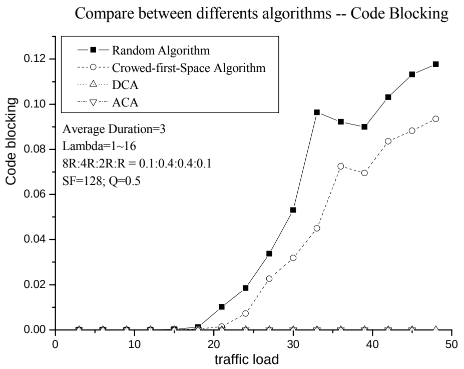


Fig.7 Code blocking

Furthermore, the proposed ACA algorithm outperforms the DCA algorithm when the total blocking is considered. The total blocking comparison between ACA algorithm and other algorithms is shown in Fig. 8. It is shown that the performance of the ACA algorithm is the best when compared to the other algorithms.

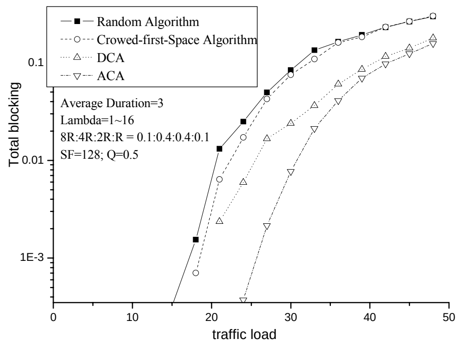


Fig.8 Total Blocking compare with other algorithms

4.1.2 Comparison of complexity

Complexity is an important factor to evalue the performance of different algorithms. For easily, here define once do one time comparation, or once sum the capacity, or move the code to one place, the complexity will increase one. The complexities can be roughly calculated according to the value of SF, the ratio of different rates, the number of users as well as the code assignment algorithms.

Random algorithm has the lowest complexity given as

$$N_{complex} \approx L \cdot P_{8R} \cdot \frac{SF}{8} + L \cdot P_{4R} \cdot \frac{SF}{4} + L \cdot P_{2R} \cdot \frac{SF}{2} + L \cdot P_R \cdot SF \quad (10)$$

The complexity of DCA algorithm is calculated as [13]

$$\begin{aligned} &N_{complex} \\ &\approx L \cdot P_{8R} \cdot (\frac{SF}{8} \times 2 + \frac{1}{2} \cdot \frac{SF-8}{4} \times 2 + \frac{1}{2} \cdot \frac{SF-8-4}{2} \times 2 + \frac{1}{2} \cdot \frac{SF-8-4-2}{1}) \\ &+ L \cdot P_{4R} \cdot (\frac{SF}{4} \times 2 + \frac{1}{2} \cdot \frac{SF-4}{2} \times 2 + \frac{1}{2} \cdot \frac{SF-4-2}{1}) \\ &+ L \cdot P_{2R} \cdot (\frac{SF}{2} \times 2 + \frac{1}{2} \cdot \frac{SF-2}{1}) + L \cdot P_R \cdot SF \end{aligned} \quad (11)$$

The complexity of the crowed-first-space algorithm [8] expresses as Eq. (12).

$$N_{complex} \approx L \cdot P_{8R} \cdot (\frac{SF}{8} \times 2) + L \cdot P_{4R} \cdot (\frac{SF}{4} \times 2) + L \cdot P_{2R} \cdot (\frac{SF}{2} \times 2) + L \cdot P_R \cdot SF \quad (12)$$

Finally, the complexity of the proposed ACA algorithm is denoted in Eq. (13).

$$\begin{aligned} &N_{complex} \\ &\approx (1-Q) \cdot (L \cdot P_{8R} \cdot N_{8R} + L \cdot P_{4R} \cdot N_{4R} + L \cdot P_{2R} \cdot N_{2R} + L \cdot P_R \cdot N_R) \\ &+ Q \cdot \left[L \cdot P_{8R} \cdot (\frac{SF}{8} \times 2) + L \cdot P_{4R} \cdot (\frac{SF}{4} \times 2) + L \cdot P_{2R} \cdot (\frac{SF}{2} \times 2) + L \cdot P_R \cdot SF \right] \\ &+ \frac{1}{3} \cdot (L \cdot P_{8R} \cdot \frac{SF}{8} + L \cdot P_{4R} \cdot \frac{SF}{4} + L \cdot P_{2R} \cdot \frac{SF}{2} + L \cdot P_R \cdot SF) \end{aligned} \quad (13)$$

According to (10)~(13), the complexities of these algorithms are listed in Table 3.

Table 3

Complexities of different code assignment algorithms

Algorithm	Random	Crowed -first-space	DCA	ACA
Complexity	52.8*L*	92.8*L*	181.7*L*	67.4*L*

while *L* is the number of users.

Through the comparisons between the blocking probabilities and complexities, it is found that the proposed algorithm can achieve the best performance but with a relatively low complexity.

4.2. Characteristics of the ACA algorithm

4.2.1 Effect of rate ratio on the total blocking

The effect of the rate ratio on the average total blocking probability and the total blocking probabilities of different rates are considered first, as shown in Fig. 9 and Fig. 10, respectively.

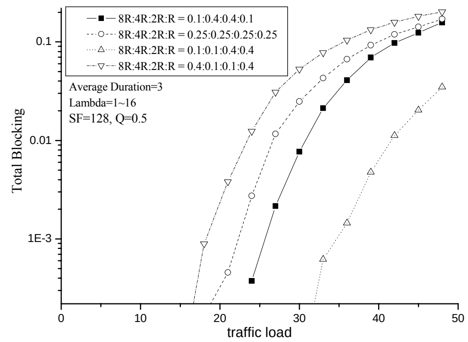
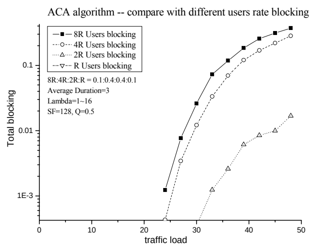
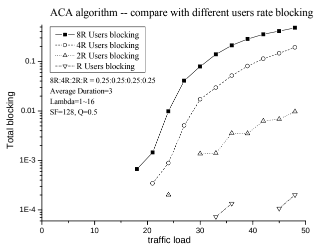
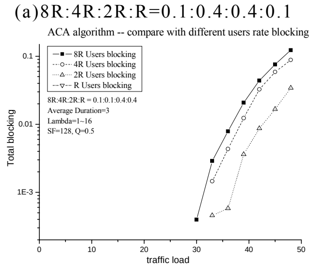


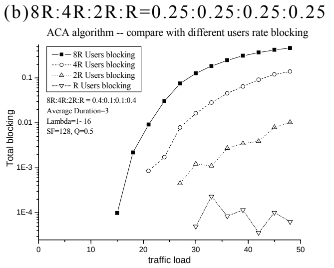
Fig.9 average blocking for different rate ratio





(a)8R:4R:2R:R=0.1:0.4:0.4:0.1 (b)8R:4R:2R:R=0.25:0.25:0.25:0.25





(c)8R:4R:2R:R=0.1:0.1:0.4:0.4 (d)8R:4R:2R:R=0.4:0.1:0.1:0.4

Fig.10 blocking for different user rate

It is shown that the more the lower-rate users are, the lower the total blocking probability is. In addition, the improvement gained by the lower rates is more significant. The reason behind is straight forward.

4.2.2 The effect of Q on the blocking

Next, the effect of the value of Q, which represents the ratio between reserved space and free space, on the blocking probabilities will be studied. The effects of Q on the average total blocking and on the total blocking corresponding to different rates are shown in Fig. 11 and Fig. 12, respectively.

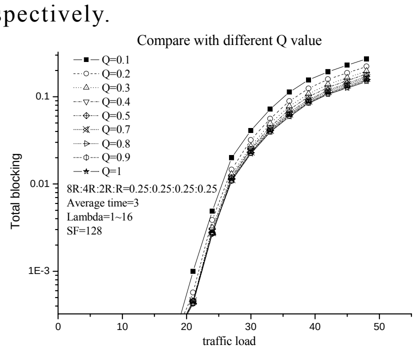
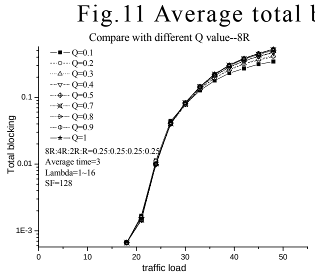
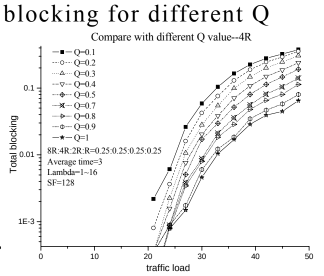
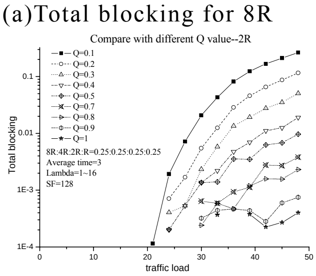


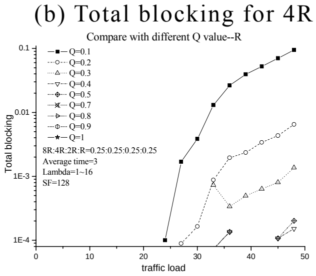
Fig.11 Average total blocking for different Q





(a)Total blocking for 8R (b) Total blocking for 4R





(c) Total blocking for 2R (c) Total blocking for R

Fig.12 blocking for different rate user

An improvement of the average total blocking probability can be observed when Q increases. However, the effects of Q on different user rates are different. It is shown that the improvement on the low-rates is more significant (the total blocking probability corresponding to rate R reduces to 0 when Q exceeds 0.5). However the blocking of users with higher rate (8R) will become larger, and the complexity will increase as the increscent of Q. Generally, if the probability of users with lower rater is higher, the Q should be larger; while the probability of users with higher rate increasing ,the Q smaller is better.

5. Conclusions

This paper has proposed an adaptive code assignment algorithm for OVSF CDMA system. This algorithm performs the code assignment adaptively according to the user rates. It has been shown by the simulation results that the proposed algorithm can improve the total blocking probability significantly but with comparatively low complexity.

Reference

[1] F. Adachi, “Wireless past and future-Evolving mobile communications systems”, IEICE Trans. Fundamentals, vol.E84-A, no.1, pp.55-60, Jan. 2001.

[2] F. Adachi, D. Garg, S. Takaoka, and K. Takeda, “Broadband CDMA techniques”, IEEE Wireless Commun., vol.12, no.2, pp.8-18, April 2005.

[3] T. Ottosson and A. Svensson, “On schemes for multirate support in DS/CDMA”, J. Wireless Personal Commun., vol.6, no.3, pp.265-287, March 1998.

[4] F. Adachi, T. Sao, and T. Itagaki, “Performance of multicode DS-CDMA using frequency domain equalization in a frequency selective fading channel,” Electron. Lett., vol.39, no.2, pp.239-241,Jan. 2003.

[5] LeLiu, Fumiyuki Adachi, “2-Dimensional OVSF Spread/Chip-Interleaved CDMA” IEICE.Commun., vol.E89-B, NO.12, pp.3363-3375, Dec. 2006

[6] F. Adachi, M. Sawahashi, and K.Okawa, “Tree structured generation of orthogonal spreading codes with different lengths for forward link of DS-CDMA mobile radio,” Electron. Lett., vol.33, pp.27-28, Jan. 1997

[7] D.S.Saini and S.V.Bhooshan, “Adaptive assignment scheme for OVSF codes in WCDMA”, proceedings of IEEE ICWMC, Bucharest, pp.65-65, July 22006.

[8] C.M.Chao, Y.C.Tseng and L.C.Wang, “Reducing Internal and External Fagmentations of OVSF Codes in WCDMA Systems with Multiple codes,” IEEE Trans. Wireless Commun., vol.4., page 1516-1526, July 2005.

[9] Y.C.Tseng, C.M.Chao, and S.L.., “Code placement and replacement strategies for wideband CDMA OVSF code tree management,” in proc. of IEEE GLOBECOM, vol. 1, pp.526-566, 2001.

[10] D.S.Saini and S.V.Bhooshan, “Assignment and Reassignment Schemes for OVSF Codes in WCDMA,” in proc of IWCMC 2006, Vancouver, pp. 497-502July 2006.

[11] W.-T. Chen, Y.-P. , and H.-C. Hsiao, “A novel code assignment scheme for W-CDMA systems,” in Proc. IEEE Vehicular Technology Conf. (VTC), Atlantic City, NJ, 2001, vol. 2, pp. 1182–1186.

[12] Y. Yang and T.-S. P. Yum, “Nonrearrangeable compact assignment of orthogonal variable-spreading-factor codes for multi-rate traffic,” in IEEE Vehicular Technology Conf. (VTC), Atlantic City, NJ, 2001, vol. 2, pp. 938–942.

[13] T. Minn and Kai.-Yeung. Siu, “Dynamic assignment of orthogonal variable spreading-factor codes in W-CDMA,” IEEE J. Select. Areas Commun., vol. 18, no. 8, pp. 1429–1440, Aug. 2000.

[14] Dian Gong, Yusong Yan, and Jianhua Lu, “Dynamic code assignment for OVSF code system,” IEEE Globecom, vol 5, pp. 2865-2869, 2005

[15] R. Assarut, K. Kawanishi, U. Yamamoto, Y. Onozato, and M.Matsushita, “Region division assignment of orthogonal variable spreading-factor codes in W-CDMA,” in Proc. IEEE Vehicular Technology Conf. (VTC), Atlantic City, NJ, 2001, vol. 3, pp. 1884–1888.

[16] Davinder S. Saini and Sunil V. Bhooshan, “Adaptive assignment scheme for OVSF codes in WCDMA,”wireless and mobile communications, ICWMC, pp.65-65, 2006

[17] Sekine, Y.; Kawanishi, K.; Yamamoto.U,and Onozato, Y, “Hybrid OVSF code assignment scheme in W-CDMA,” coomunication, commuters and signal processing, PACRIM, vol 1, pp.384-387, 2003

[18] Jun-Seong Park and Daniel C.Lee, “On static and dynamic code assignment policies in the OVSF code tree for CDMA networks,” MILCOM processings, vol.2, pp, 785-789, 2002

[19] Merani, M.L.and Pettenati, M, “How to Veritably Determine the Accomplishments of Static and Dynamic OVSF Code Assignment Algorithms,” Personal, Indoor and Mobile Radio Communications, IEEE 17th International Symposium, pp.1-6, 2006