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Fast dynamic code assignment in next generation wireless access networks

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Abstract

In this paper, a fast dynamic code assignment (FDCA) algorithm is proposed to assign a single Orthogonal Variable Spreading Factor (OVSF)-code for a data rate requirement in next generation wireless access networks. Our algorithm uses the code assignment operation to evaluate the cost for an OVSF-code allocation. The cost is determined by maintaining the data structure that keeps track the number of available and occupied descendant codes of the code. Based on the cost assignment operation, FDCA algorithm can assign an OVSF-code by reassigning occupied descendant codes for a requested data rate. The OVSF-codes assigned by our algorithm is unrestricted with decreasing spreading factor. Moreover, two types of simulations and experimental measurements are presented. First, the proposed algorithm is applied on the OVSF-code assignment of restricted spreading vector. Our experimental results show that the number of reassigned OVSF-codes within FDCA algorithm is reduced comparing to other scheme proposed in the literature. Then, for serving higher data rate requirements, our scheme also shows significant improvement on the spectral efficiency over fixed code assignment scheme.

Keywords: Channelization code; Spreading factor; Code-tree; Dynamic code assignment

1. Introduction

In recent years, mobile communication services have increased rapidly. Since current (GSM/GPRS) mobile systems provide only basic services, such as voice traffic and low-rate data services, the third generation (3G) mobile systems have been developed to support a wider variety of services. The 3G mobile systems improve spectral efficiency to increase the system capacity, which provide higher quality voice, real-time data and high-rate multimedia services [1]. Wideband Code Division Multiple Access (WCDMA) [2,3] is the most popular radio access technology system that was proposed by the 3rd Generation Partnership Project (3GPP) and complies with IMT-2000 standards [4].

To provide different services and multimedia applications, WCDMA must support high-rate bandwidth and variable-rate transmission [5]. Furthermore, it allows the data rate of a call to change based on time or frame. The resource allocation mechanism of WCDMA must contain features, including dynamic code assignment (DCA), which performs the channelization code assignments within real-time operation mode. In a WCDMA system, the channelization code assignments are based on the Orthogonal Variable Spreading Factor (OVSF) technique [6,7]. Using allocated channelization code [8], the upper layer information signals can be spread into 3.84 Mchip/s and transmitted to the air interface. To satisfy the variable-rate data requirements, the DCA must assign channelization codes according to the adaptive spreading factors (SFs), which in turn satisfy the data rate of a call.

There are two distinct strategies to provide variable-rate transmissions, which can be classified as either single-code transmission [6,9,10] or multi-code transmission [11,12]. Dahlman and Jamal [13] described these strategies in detail and concluded that although each approach has its advantages, and none is better than other. The multi-code

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transmission complicates hardware implemented because it must simultaneously control the coding/decoding of multiple transceiver units. For terminal amplifier efficiency, multi-code transmission increases the peak-to-average ratio of a transmission channel. The supported multi-code transmission is also restricted by the capability of user equipment, such as the Rake receivers of mobile terminals. Notably, this is beneficial with single-code transmission that increases the efficiency of the terminal power amplifier. In a single-code transmission, however the assignment of the basic rate OVSF-code is limited to a multiple of 2^n, which causes coarsely quantized data rate as well as leading lower data efficiency. Particularly within a WCDMA system, a single-code transmission can be employed to support the varying data rates. However, when a higher data rate (2 M bps) is requested, this system has to assign three OVSF-codes of low spreading factor (SF $= 4$) at the same time to support the data rate of the requirement.

Different strategies of OVSF-code assignment have been proposed. Cheng [11] proposed an algorithm that uses multi-code transmission to support the variable-rate of data services. He employed data structures to track information concerning the assigned code and available codes within an OVSF-code tree. Applying the information, an algorithm is proposed to obtain several OVSF-codes according to the requested data rate. The method for OVSF-code selecting is to use lower spreading factor codes, rather than fewer codes, with a higher spreading factor. Although, this method increases the efficiency of the radio spectrum resource, using more OVSF-codes increases the Rake combiners in mobile terminals. To overcome the shortcoming, Shueh et al. [10] presented a flexible multi-code assignment scheme that could reduce the number of Rake combiners of mobile terminals.

Minn and Siu [9] discussed the assignment of OVSF-codes by the single-code transmission method. The basic idea of their algorithm is to list all allocated codes within both a 3- and 4-layered sub-trees of an OVSF-code tree. Furthermore, they defined costs for the assigning OVSF-code according to whether the descendant codes of the OVSF-code of a sub-tree are occupied. If a sub-tree contains more occupied codes, it is necessary using a higher cost to reassign these occupied codes into other alternate sub-trees. In order to determine a minimum cost of a reassignment, Minn and Siu discussed several comparison rules according to all topologies of 3-layered sub-trees. However, when a sub-tree had four layers, they classified at least 85 comparison rules. Moreover, the comparison rules grow exponentially with the code-tree layers. Therefore, when there are more than four layers, it is difficult to list all the comparison rules according to the topological code-tree.

In this paper, a fast dynamic code assignment (FDCA) algorithm is proposed. The proposed algorithm is to minimize code assignment with a single-code allocation. The contribution of this paper is that we can assign fast and efficiency OVSF-code for a requested high-rate data service. Since it is unnecessary to analyze the topological code-tree of the occupied codes within a sub-tree in advance, our algorithm simply the code assignment of Ref. [9].

This paper is organized as follows. Section 2 reviews OVSF-codes and describes the allocation scheme under various data rates. Section 3 presents the proposed FDCA algorithm, which assigns OVSF-code to the required data user. Section 4 analyzes the simulation results and illustrates the effectiveness of the proposed algorithm as compared to previous studies. Finally, concluding remarks are given in Section 5.

2. Channelization code and its allocation

WCDMA is the most popular radio access system in the major areas of the whole world. It uses channelization codes to increase spectrum efficiency and provides various data rates based on the codes assignments. In this section, we describe the properties of channelization codes and present the basic techniques for channelization code allocation.

2.1. OVSF-code

WCDMA system requires a variety of data services, from low to high data rates. According to the requested data rate, the system assigns channelization codes that employ orthogonal spreading to distinguish data from the physical channels and thus, prevents data transmission interference from varying resources. The basic operations of spreading and dispreading for WCDMA are discussed in Ref. [2]. Generated channelization-codes, which are based on OVSF techniques, have been described in Ref. [8]. Fig. 1 illustrates the OVSF-code structure. Each node within a code-tree denotes an OVSF-code, known as code. The code-tree is built up after each code, $C_{i,j} = \{a\}$, adds with its two children codes, $C_{2i,2j-1} = \{a, a\}$ and $C_{2i,2j} = \{a, -a\}$, where i and j denotes SF and code number, respectively. A large SF code is applied for a lower requested data rate, and a small SF code is used for a higher data rate. Besides its

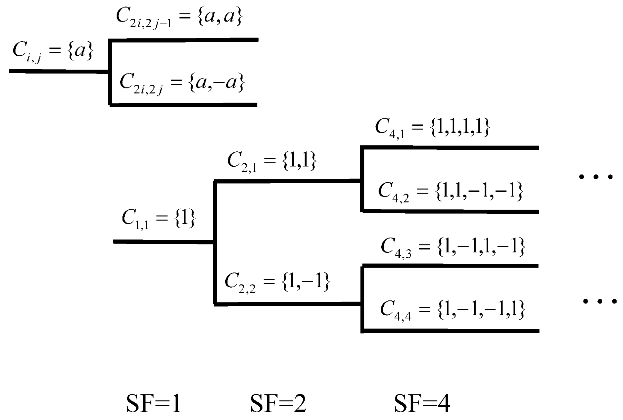

Fig. 1. The OVSF code-tree structure.

Table 1
OVSF code-tree layers and their SFs

Layer	1	2	3	4	5	6	7	8	9	10
Spreading factor	1	2	4	8	16	32	64	128	256	512
# of Codes	1	2	4	8	16	32	64	128	256	512
Data rate	2^9R	2^8R	2^7R	2^6R	2^5R	2^4R	2^3R	2^2R	$2R$	$1R$

ascendant and descendant codes, every code is orthogonal with each other in a code-tree. However, there are certain restrictions in which a single source uses a code for transmission. To retain the orthogonal from alternate sources, a physical channel cannot use a certain root-code of a sub-tree within a code-tree if its descendant codes have been assigned to another physical channel. Consequently, it can only use the assigned code until all of its occupied descendant codes are released.

In a WCDMA system, an OVSF code-tree is a 10-layered fully binary tree. Table 1 illustrates a code-tree for various SFs, which is ranging from $\mathrm{SF}=4$ to $\mathrm{SF}=512$. The number of code collocated within a layer is equivalent to the value of the spreading factor at this layer. For example, the number of code on the 1st, 2nd and 3rd layers equal to 1, 2 and 4, respectively, which are their spreading factor value. Consequently, if the layer is increased by 1, the number of codes is increased by the order of 2^n. The codes within the lower layer of a code-tree provide a higher data rate. Thus, if the provided data rate at the highest layer (i.e. 10th layer) is rate R, rate $2R$, rate 2^2R to rate 2^9R can be provided at the lower layers. The system can manage the code assignment in a manner that allocates one code $C_{i,j}$ for a $2^{10-i}R$ rate service, or two descendent codes $C_{2i,2j-1}$ and $C_{2i,2j}$ for two alternate $2^{9-i}R$ rate services. In some case, if 1/2-rate coding technique is used, the $\mathrm{SF}=512$ codes provide a data rate of up to 3 kbps within a WCDMA system. In addition, with $\mathrm{SF}=4$, the maximum data rate can provide up to 936 kbps. Three $\mathrm{SF}=4$ codes can be employed simultaneously to support a maximum 2 Mbps data rate [2].

2.2. Dynamic code assignment

Using OVSF-code assignment, some codes may be blocked after a period of time. This occurs when lower call data rate occupied numerous descendant codes of a higher-rate code. To decrease the blocking rate of a code-tree, we can use the DCA scheme to free the blocking code by reassigning the occupied codes to another sub-tree.

For example, Fig. 2(a) depicts calls S_1, S_2 and S_3, where the requested data rates are R, $2R$ and R, respectively. After executing the code assignment algorithm, the system may assign code $C_{4,1}$ to S_1, code $C_{3,2}$ to S_2, and code $C_{4,6}$ to S_3, respectively. Note that the remaining capacity of the code-tree becomes $4R$. Subsequently, a new call, S_4, arrives and the requested data rate is $4R$. Consequently, codes $C_{2,1}$ and $C_{2,2}$ are blocked because the descendant codes of $C_{2,1}$ (i.e. $C_{3,2}$ and $C_{4,1}$) and $C_{2,2}$ (i.e. $C_{4,6}$) are occupied. In order to support the capacity for requirements of S_4, one DCA scheme may be applied to use $C_{2,1}$ and to reassign S_1 to $C_{4,5}$

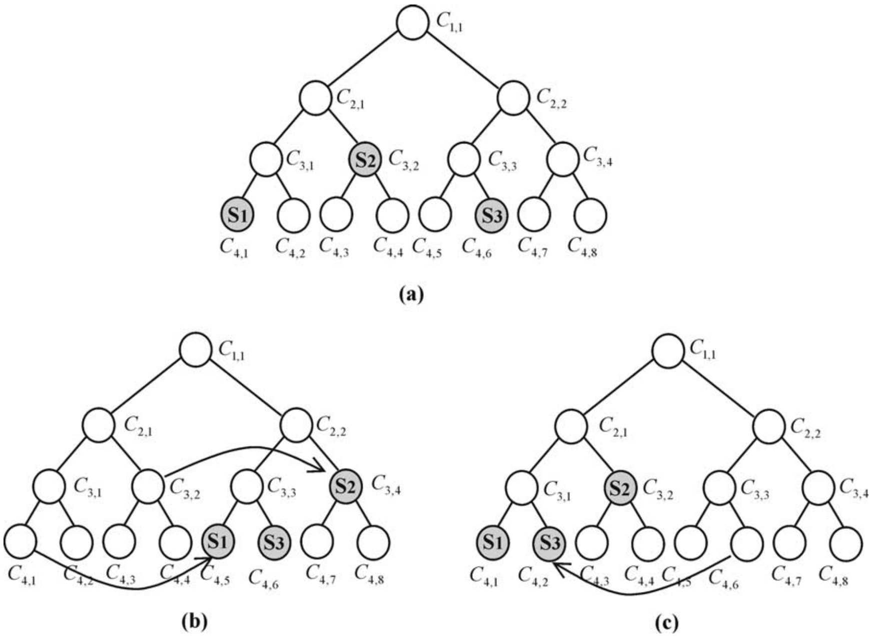

Fig. 2. The DCA scheme of reassigned occupied codes.

and S_2 to $C_{3,4}$ (Fig. 2(b)). However, another DCA scheme may decide to use code $C_{2,2}$ for the new call and reassign code $C_{4,2}$ to S_3 (Fig. 2(c)). Apparently, the second scheme is better because only one code requires reassignment.

3. The proposed algorithm

In this section, we present a FDCA algorithm to implement the OVSF-code allocation for the data rate requirements. Our algorithm uses two schemes to choose an OVSF-code such that the cost of the selected code assignment is small. First, we evaluate the cost of a code by applying cost assignment scheme. For a blocked code, the cost is defined as the number of occupied descendant codes that are reassigned to other codes for the code availability. Then, when a call request arrives, the FDCA algorithm assigns a suitable code to meet the data requirement based on the following cost assignment scheme.

3.1. Cost assignments

Since WCDMA relies on the 10-layered OVSF-code tree, the system has the code element assignments on the rates $1R, 2R, 4R, 8R$, etc. up to the root code rate $512R$. For a call request, it is possible that the selected code will be blocked. The cost assignment scheme is used to evaluate the cost for the reassignment of the blocking code. We now state the scheme as follows.

The cost assignment scheme maintains the codeword structure. This codeword structure is to keep track the number of available and occupied descendant codes for a selected code. Thus, if the selected code is blocked because at least one of its descendant codes is occupied, we can employ the information of the codeword structure to calculate the possible cost when we reassign occupied descendant codes to other codes. The notations for specifying the cost assignment scheme are as follows:

- $T = \{C_{i,j} | 1 \le i \le 10,\ 1 \le j \le 2^{i-1}\}$ denotes the OVSF-codes of the 10-layered code-tree T, where $C_{i,j}$ is the i-level and j-order code of T.
- $D_{i,j\_avail} = (d_1, d_2, \ldots, d_9, d_{10})$, where d_k denotes the number of k-level available descendant codes of $C_{i,j}$. If $k < i$, $d_k = 0$.
- $D_{i,j\_used} = (u_1, u_2, \ldots, u_9, u_{10})$, where u_k denotes the number of k-level occupied descendant codes of $C_{i,j}$. If $k < i$, $u_k = 0$, and $d_i + u_i \le 2^{i-1}$.
- $E_{i,j\_avail} = (a_1, a_2, \ldots, a_9, a_{10})$ denotes a codeword that indicates the number of available codes of T, but excluding the available descendant codes of $C_{i,j}$ (i.e. D_{i,j_avail}).
- $D_{i,j\_reassign} = (r_1, r_2, \ldots, r_9, r_{10})$, where r_k denotes the number of reassigned k-level occupied descendant codes of $C_{i,j}$.

Table 2
Pseudo program of Evaluate_Cost_Procedure($C_{i,j}$) ($C_{i,j}$: OVSF code)

P_0: Initiate $D_{1,1\_avail} \leftarrow (d'_1, d'_2, \ldots, d'_9, d'_{10})$;
$D_{i,j\_avail} \leftarrow (0, \ldots, 0, d_i, \ldots, d_9, d_{10})$;
$D_{i,j\_used} \leftarrow (0, \ldots, 0, u_i, \ldots, u_9, u_{10})$;
P_1: Let $E_{i,j\_avail} \leftarrow (a_1, a_2, \ldots, a_9, a_{10})$;
$E_{i,j\_avail} \leftarrow D_{1,1\_avail} - D_{i,j\_avail}$;
P_2: Let $E'_{i,j\_avail} \leftarrow (a'_1, a'_2, \ldots, a'_9, a'_{10})$;
$(a'_1, a'_2, \ldots, a'_9, a'_{10}) \leftarrow (a_1, a_2, \ldots, a_9, a_{10})$;
For ($\forall u_k \in D_{i,j\_used}$, where k from i to 10)
$P_{2.1}$: If ($a_k \ge u_k$), then $a'_k \leftarrow a_k$;
$P_{2.2}$: If ($a_k < u_k$ and $\{a_p \| a_p \ne 0,\ 1 \le p \le k-1\}$ existing),
then $a'_k \leftarrow a_k + 2^{k-p}$; $a'_p \leftarrow a'_p - 1$;
Repeat until ($a'_k \ge u_k$ or $\{a_p \| a_p = 0,\ 1 \le p < k\}$);
$P_{2.3}$: If ($a_k < u_k$ and $\{a_p \| a_p \ne 0,\ 1 \le p < k\}$ not existing),
$a'_k \leftarrow a_k$;
P_3: Let $D_{i,j\_reassign} \leftarrow (r_1, r_2, \ldots, r_9, r_{10})$;
$D_{i,j\_reassign} \leftarrow E'_{i,j\_avail} - (E_{i,j\_avail} - D_{i,j\_used})$;
P_4: $N(D_{i,j\_reassign}) \leftarrow \sum_{k=1} r_k$

- $N(D_{i,j\_reassign})$ denotes the amount of reassigned occupied descendant codes of $C_{i,j}$ to free the code $C_{i,j}$.

The pseudo program for evaluating the costs for code availabilities is presented in Table 2. In Table 2, we assume that code $C_{i,j}$ is blocked. Initially, Step (P_0) generates codewords $D_{1,1\_avail} = (d'_1, d'_2, \ldots, d'_9, d'_{10})$, $D_{i,j\_avail} = (0, \ldots, 0, d_i, \ldots, d_9, d_{10})$, $D_{i,j\_used} = (0, \ldots, 0, u_i, \ldots, u_9, u_{10})$ in terms of the current code allocation. By definition, let $E_{i,j\_avail} = (a_1, a_2, \ldots, a_9, a_{10})$, here E_{i,j_avail} is defined by Eq. (1) (Step (P_1)),

$$E_{i,j\_avail} = D_{1,1\_avail} - D_{i,j\_avail} = (d'_1, d'_2, \ldots, d'_9, d'_{10}) - (0, \ldots, 0, d_i, \ldots, d_9, d_{10}) \quad (1)$$

where $D_{1,1\_avail}$ denotes a codeword. In this codeword, all entries indicate the available code numbers of root code. In this example, we assume that the total available code rate of E_{i,j_avail} is greater than the total occupied code rate of D_{i,j_used}. The following formula gives a precise definition,

$$\sum_{k=1}^{10} a_k 2^{k-1} R \ge \sum_{k=1}^{10} u_k 2^{k-1} R \quad (2)$$

For example, Fig. 3(a) illustrates a 6-layered code-tree that can provide the maximum code rate of $32R$. After running a period of time, some of the codes become occupied by some mobile users. The 6-layered code-tree is denoted as $T = \{C_{i,j} | 1 \le i \le 6,\ 1 \le j \le 2^{i-1}\}$. Consider that a new call arrives that requests $16R$ code rate. We assign code $C_{2,2}$ to the new call. In this example, code $C_{2,2}$ only has one availably 4-level code $C_{4,8}$, and three other 4-level codes $C_{4,5}$, $C_{4,6}$ and $C_{4,7}$ are occupied by other mobile users. Consequently, the codewords for $C_{2,2}$ are $D_{2,2\_avail} = (0,0,0,1,0,0)$ and $D_{2,2\_used} = (0,0,0,3,0,0)$. Since $D_{1,1\_avail} = (0,0,1,1,1,2)$, $E_{2,2\_avail} = (0,0,1,0,1,2)$ can be obtained by Eq. (1). Therefore, the current available code rate, denoted by $E_{2,2\_avail}$, is $12R$, which equals to

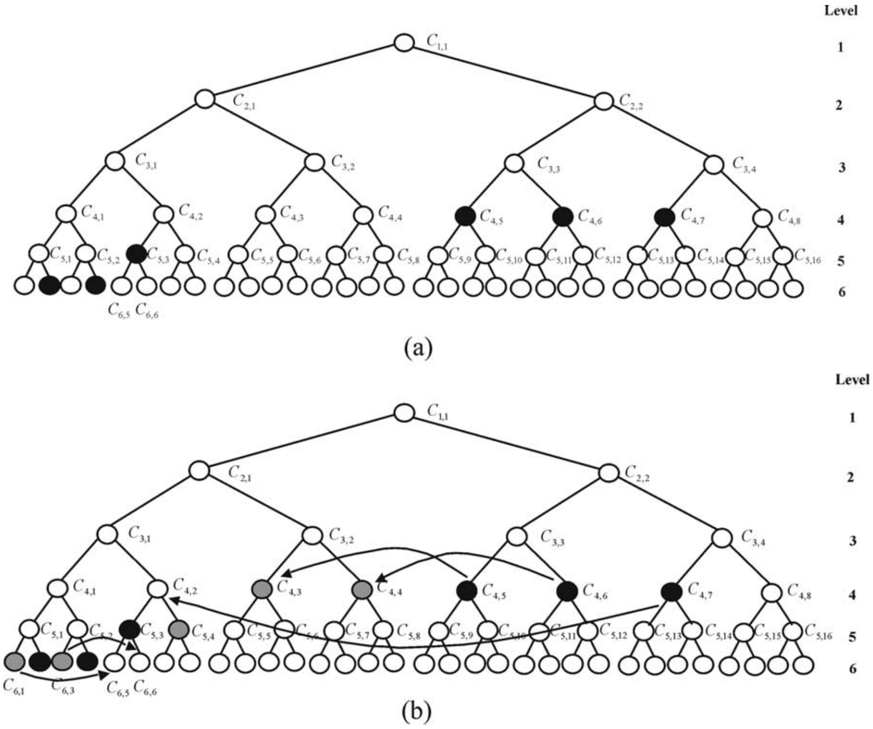

Fig. 3. Code assignment of a 6-layered code-tree. (a) Before code reassignments. (b) The usage of $C_{2,2}$ for code rate 16R supporting.

the occupied amount rate 12R, denoted by $D_{2,2\_used}$. To make code C_{22} available, the occupied descendant codes of $C_{2,2}$, that are $C_{4,5}$, $C_{4,6}$ and $C_{4,7}$, should be reassigned to the available codes outside the sub-tree rooted by $C_{2,2}$, that is $E_{2,2\_avail}$. The rate of 3-level available code $C_{3,2}$ is the double of the rate of 4-level code $C_{4,5}$ (or $C_{4,6}$ and $C_{4,7}$). Thus, we can immediately reassign two codes $C_{4,5}$ and $C_{4,6}$ to $C_{3,2}$'s descendant codes $C_{4,3}$ and $C_{4,4}$, respectively. Consequently, codeword $E_{2,2\_avail} = (0,0,1,0,1,2)$ has become codeword $E'_{2,2\_avail} = (0,0,0,2,1,2)$ to reflect this code allocation.

Step (P_2) illustrates the implementation of the codewords translation from E_{i,j_avail} to E'_{i,j_avail}. For a blocking code $C_{i,j}$, we reassign $C_{i,j}$'s occupied descendant codes to the available codes of other branches outside the sub-tree rooted by $C_{i,j}$. Let $E'_{i,j\_avail} = (a'_1, a'_2, \ldots, a'_9, a'_{10})$. For $\forall a_k \in E_{i,j\_avail}$ and $\forall u_k D_{i,j\_used}$, the codeword translation is performed repeatedly from Step ($P_{2,1}$), ($P_{2,2}$) to Step ($P_{2,3}$). In Step ($P_{2,1}$), if $a_k \geq u_k$, then $a'_k = a_k$. Thus, the k-level occupied codes of $C_{i,j}$ can be immediately assigned to k-level available codes. In Step ($P_{2,2}$), if $a_k < u_k$ and there exists any available lower-level code of other branches. We reassign $C_{i,j}$'s k-level occupied codes to the descendant codes of that lower-level code. This means that a_k can borrow digits from its left place, and we have $a'_k = a_k + 2^{k-p}$, $a'_p = a_p - 1$, where $1 \leq p \leq k-1$. We repeat the same step while ($a'_k \geq u_k$ or $\{a_p | a_p = 0,\ 1 \leq p < k\}$) is successful. After that, if $a_k < u_k$ and there is no the available lower-level code of other branches, Step ($P_{2,3}$) is performed. Then, we execute $a'_k = a_k$.

Consider a system, the available code rate in the system after assignment equals to the available code rate before assignment minus the rate requested by the mobile users. Thus, the allocated code rates in the reassignment process would be denoted as $D_{i,j\_reassign} = (r_1, r_2, \ldots, r_9, r_{10})$, where $D_{i,j\_reassign} = (r_1, r_2, \ldots, r_9, r_{10})$ can be obtained by Eq. (3) (Step (P_3)),

$$D_{i,j\_reassign} = E'_{i,j\_avail} - (E_{i,j\_avail} - D_{i,j\_used}) \quad (3)$$

Since $\forall r_k \in D_{i,j\_reassign}$ is the code number used for the code reassignment, the estimation cost of the reassigned codes number, $N(D_{i,j\_reassign})$, can be represented by Eq. (4) in Step P_4,

$$N(D_{i,j\_reassign}) = \sum_{k=1} r_k, \qquad \forall r_k \in D_{i,j\_reassign} \quad (4)$$

Consider the example of Fig. 3(a). Codeword $E'_{2,2\_avail}$ can be obtained by,

$$E'_{2,2\_avail} = (0,0,0,2,1,2) \qquad \text{(Step (P2))}$$

The code rate provided by the system after reassignment can be obtained by the following results,

$$E_{2,2\_avail} - D_{2,2\_used} = (0,0,1,0,1,2) - (0,0,0,3,0,0)$$

$$= (0,0,0,0,0,0)$$

Codeword $D_{2,2\_reassign}$ can be obtained by,

$$D_{2,2\_reassign} = E'_{2,2\_avail} - (E_{2,2\_avail} - D_{2,2\_used})$$

$$= (0,0,0,2,1,2) - (0,0,0,0,0,0)$$

$$= (0,0,0,2,1,2)$$

(Step (P3))

As a result, to free the code C_{22}, the approximated cost for reassigning occupied descendant codes of C_{22} to other codes is (Fig. 3(b)),

$$N(D_{2,2\_reassign}) = \sum 2 + 1 + 2 = 5 \qquad \text{(Step(P4))}$$

3.2. FDCA Algorithm

The FDCA algorithm can support variable-rate data using single-code assignment. In order to assign a suitable code for a requested data rate, FDCA keeps track the code allocations of all OVSF-codes within a code-tree. As discussed above, the FDCA algorithm applies cost assignment by procedure Evaluate_Cost_Procedure() to evaluate the cost of a code for a new call requested. Furthermore, if a code is blocked, the algorithm can find a good scheme to reassign all occupied descendant codes of this code such that this code is free after the reassignment. Our simulation shows that this scheme is superior to other DCA schemes. Table 3 shows the pseudo program of FDCA algorithm. The FDCA algorithm is described as follows:

(1) To initiate the algorithm, we create all codewords of the code elements within a code-tree. The status of their available descendant codes and occupied descendant codes is stored in these codewords. That is, D_{i,j_avail} and D_{i,j_used}, where $1 \le i \le 10$ and $1 \le j \le 2^{i-1}$ (Step (P_1)).

(2) Step (P_2) is a loop, and at every iteration of the loop, a new call arrives. For a new call S, the algorithm first determines whether the requested data rate can be supported by the system capacity, denoted by the value of $D_{1,1\_avail}$. If it is true (Step ($P_{2,1}$)), go to Step (P_3), otherwise (Step ($P_{2,2}$)), it means that call S is blocked.

(3) To locate the code elements that can support the requested data rate, we first search the specified level in the code-tree (Step (P_3)). Without loss of generality, assume that a code at i-level in the code-tree can support the requested data rate. Subsequently, we apply procedure Evaluate_Cost_Procedure($C_{i,j}$) to each code $C_{i,j}$ within i-level code-tree to evaluate their costs. The evaluating result is stored in $N(D_{i,j\_reassign})$. We select among all possible $N(D_{i,j\_reassign})$ a code $C_{i,j}$ with minimum cost. (Steps ($P_{3,1}$), ($P_{3,2}$) and ($P_{3,3}$)).

(4) In Steps ($P_{3,4}$), if the allocated code is blocking, we iteratively reassign all of its occupied descendant codes to other free codes such that the allocated code become available. Otherwise, if the allocated code is available, the code is assigned to call S in Steps ($P_{3,5}$). After the code assignment is complete, the codewords of the code (i.e. $D_{i,j\_reassign}$ and D_{i,j_used}) need to be changed, and the codewords of all related ascendant and descendant codes must be updated to reflect the code-tree's new status. If another new call has been received, proceed to Step P_2. Otherwise, the algorithm terminates.

Fig. 4(a) illustrates an example of the FDCA algorithm. Assume that a newly arriving call requests data rate 8R, and the system has enough capacity to support the request. The possible candidates of a code-tree, which can provide the data rate $8R$, are $C_{3,1}$, $C_{3,2}$, $C_{3,3}$, and $C_{3,4}$. Thus,

$$D_{1,1\_avail} = (000017),\ D_{1,1\_used} = (000159)$$

$$D_{3,1\_avail} = (000001),\ D_{3,1\_used} = (000111),\ E_{3,1\_avail} = (000016)$$

$$D_{3,2\_avail} = (000003),\ D_{3,2\_used} = (000013),\ E_{3,2\_avail} = (000014)$$

$$D_{3,3\_avail} = (000011),\ D_{3,3\_used} = (000013),\ E_{3,3\_avail} = (000006)$$

$$D_{3,4\_avail} = (000002),\ D_{3,4\_used} = (000022),\ E_{3,4\_avail} = (000015)$$

Next, we compute the codeword $D_{i,j\_reassign}$ for all possible candidates,

$$D_{3,1\_reassign} = (000016) - ((000016) - (000111)) = (000015)$$

$$D_{3,2\_reassign} = (000014) - ((000014) - (000013)) = (000013)$$

$$D_{3,3\_reassign} = (000006) - ((000006) - (000013)) = (000005)$$

Table 3
Pseudo program of FDCA algorithm

P_1: For ($\forall C_{i,j} \in$ Code-tree T)
Initiate the setting of codewords D_{i,j_avail} and D_{i,j_used};
P_2: While (a new call S)
$P_{2,1}$: If (requested data rate of $S \le$ Capacity($D_{1,1\_avail}$))
P_3: $C =$ Code_Reassign_Procedure (requested data rate of S);
Assign code C to call S;
$P_{2,2}$: If (requested data rate of $S >$ Capacity($D_{1,1\_avail}$))
Block S; }
P_3: Code_Reassign_Procedure (requested data rate)
$P_{3,1}$: Use i-level codes according to the requested data rate;
$P_{3,2}$: For ($\forall C_{i,j} \in i -$ level codes)
$N(D_{i,j\_reassign}) =$ Evaluate_Cost_Procedure ($C_{i,j}$); //Evaluate code costs
$P_{3,3}$: $C_{i,k} = \min(N(D_{i,1\_reassign}), N(D_{i,2\_reassign}), \ldots, N(D_{i,2^{i-1}\_reassign}))$;
$P_{3,4}$: If ($C_{I,k}$ is blocked)
For ($\forall C_{m,n} \in C'_{i,k}$s occupied descendant codes)
$C =$ Code_Reassign_Procedure ($C_{m,n}$'s code rate);
Reassign $C_{m,n}$ to C;
$P_{3,5}$: If ($C_{I,k}$ is available)
Update $C_{i,k}$'s status and its related codewords;
Return($C_{i,k}$); }

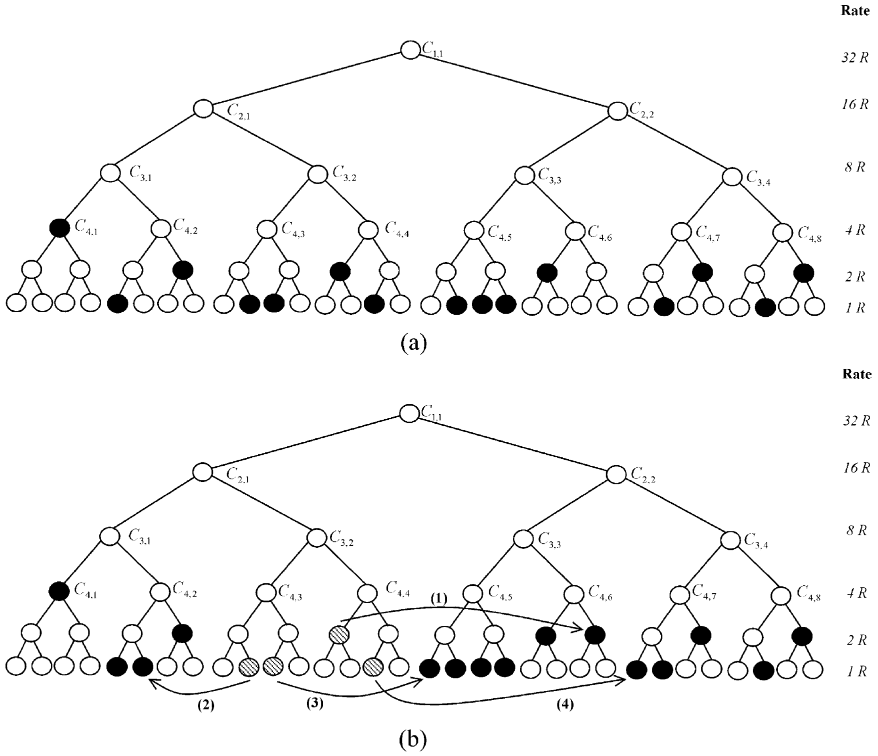

Fig. 4. Codes that are reassigned within a 6-layered code-tree. (a) Current assigned state of a code-tree. (b) After completed FDCA algorithm.

$$D_{3,4\_reassign} = (000015) - ((000015) - (000022)) = (000014)$$

Therefore,

$N(C_{3,1\_reassign}) = 6$

$N(C_{3,2\_reassign}) = 4$

$N(C_{3,3\_reassign}) = 5$

$N(C_{3,4\_reassign}) = 5$

Consequently, code $C_{3,2}$ was selected to the new call because that it has minimum reassignment cost (Fig. 4(b)).

4. Simulation results

In this section, details of our simulations are provided and results from two categories of measurement are presented. First, we consider the case that code assignment is restricted by a spreading vector. In this case, our scheme is compared to other DCA Scheme. Second, code assignments of spreading vector of requested data rates are unlimited, we do some simulation on this case.

4.1. Code assignment under limited spreading vector condition

The simulation results of code reassignment, blocked call rate and spectral efficiency were measured by implementing FDCA algorithm and Minn and Siu's DCA algorithm [9]. The simulations of these two algorithms were performed with code assignments from SF = 512 to 64. Table 4 lists the input parameters of the simulation experiments.

In our simulation, the traffic load depended on three types of input parameters. For parameters A and $1/U$, A denotes the call arrival rate, $1/U$ denotes the call duration time, and A/U indicates the number of arriving calls duration one unit of time. Parameter R represents the requested data rate for a newly arriving call. Total 10,000 calls were generated for our simulation, and the distributions of the requested data rate were 20% (R), 30% ($2R$), 30% ($4R$), and 20% ($8R$),

Table 4
Selected input parameters

Parameter	Distributed				Mean Value
A: call arrival rate	Poisson distributed				200–380 calls/unit
$1/U$: call duration time	Exponential distributed				5 units
SF: spreading vector	512	256	128	64	–
R: requested code rate	R	$2R$	$4R$	$8R$	–
	20%	30%	30%	20%	

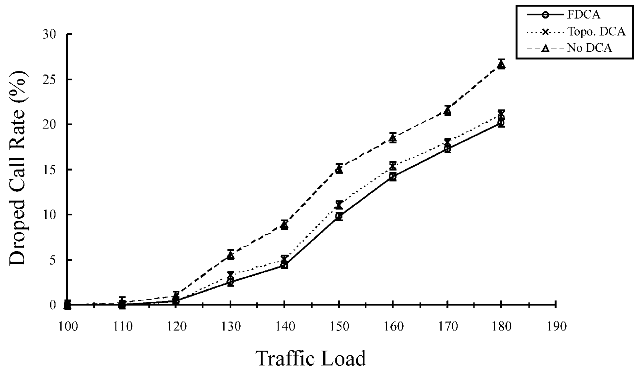

Fig. 5. Dropped call rate under 10,000 arriving calls.

respectively. By simulation, we perform 10 observations for each traffic load. The 10 observations are formed a normal distribution with mean value. We construct a 90% confidence interval for the mean value. The allocation code resources required a 10-layered code-tree to reflect the reality of an actual WCDMA.

The simulations are performed in terms of dropped call rate, code reassignment and spectral efficiency versus various traffic loads. The dropped call rate is measured according to the probability of a blocked call, when the system could not assign an available code for a newly arriving call. Decreasing the number of reassigned codes is cost-effective and can reduce the complexity of code assignment. Finally, spectral efficiency was evaluated to measure the served data rate over the total requested data rate of all incoming calls.

Figs. 5–7 illustrate the experimental results of dropped call rate, code reassignment and spectral efficiency versus traffic loads, respectively. Fig. 5 depicts that the probability of a dropped call within a heavily load condition is significantly higher than within a lighter traffic load. Alternately, the spectral efficiency of the resource decreased due to an increased traffic load (Fig. 6). Figs. 5 and 6 reveal that the dropped call rate and spectral efficiency of FDCA algorithm is superior to Minn and Siu's algorithm. However, Fig. 7 illustrates that within a heavy traffic load, the mean number of reassigned codes in our FDCA

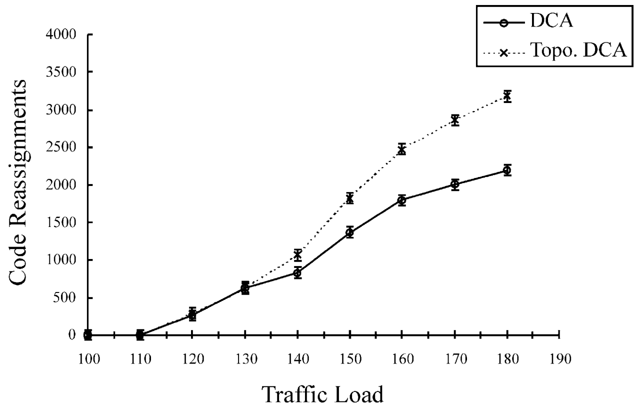

Fig. 7. Code reassignments with respect to traffic load.

algorithm is significantly less than Minn and Siu's algorithm.

4.2. Code assignment under unlimited spreading vector condition

In this case, the probability of blocked call rate and the performance of spectral efficiency were compared to the proposed FDCA algorithm and fixed code assignment scheme (i.e. without implemented DCA algorithm). The selected input simulation parameters are similar to those described previously. To simulate the actual planning of

Table 5
Selected input parameters

Parameter	Distributed					Mean value
A: call arrival rate	Poisson distributed					200–380 calls/unit
$1/U$: call duration time	Exponential distributed					5/8 units
SF: spreading vector	512	256	32	16	8	–
R : requested code rate	R	$2R$	$8R$	$16R$	$32R$	–
Case 1	10%	30%	30%	20%	10%	
Case 2	10%	20%	20%	30%	20%	

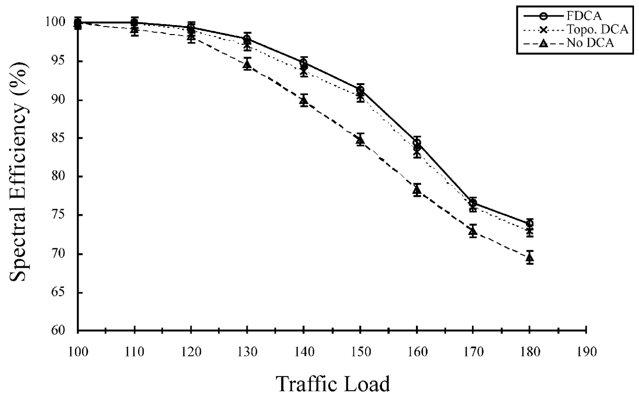

Fig. 6. Spectrum efficiency with respect to the traffic load.

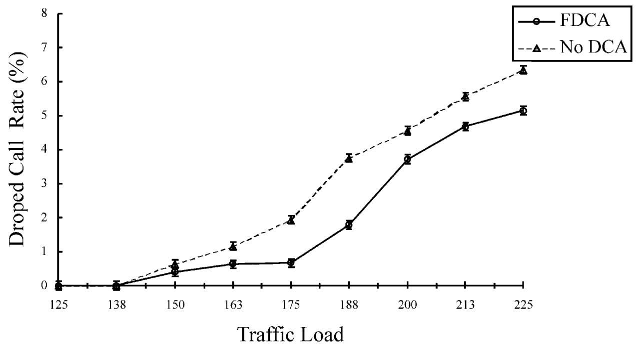

Fig. 8. Dropped call rate under 10,000 arriving calls.

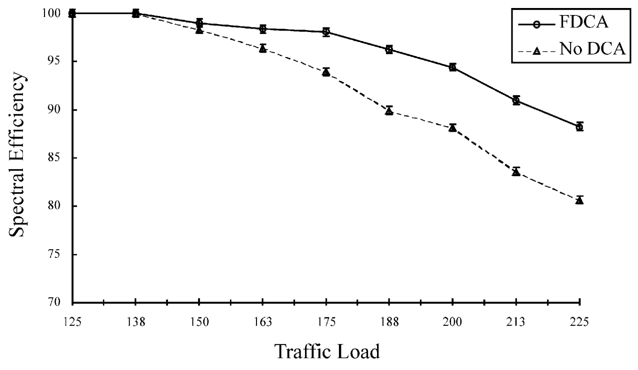

Fig. 9. Spectrum efficiency with respect to traffic load.

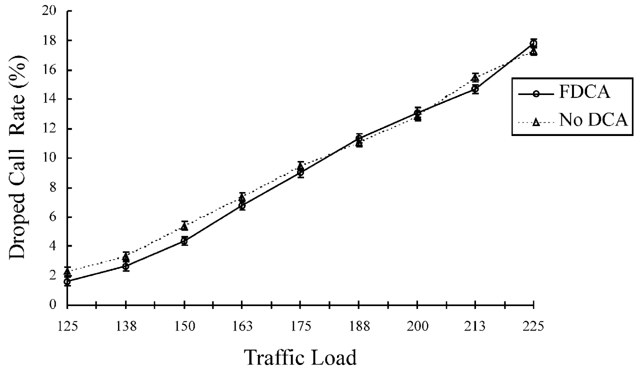

Fig. 10. Dropped call rate under 10,000 arriving calls.

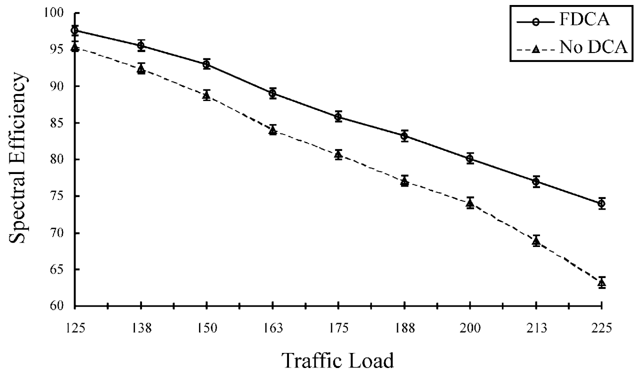

Fig. 11. Spectrum efficiency with respect to traffic load.

WCDMA network, the code assignment from SF = 512, 256, 32, 16, and 8 is simulated to reflect the requested data rate = 3, 12, 64, 144, and 256 kbps, respectively. Furthermore, to avoid a system overload, the average of call duration was decreased. Table 5 lists the simulation input parameters.

Figs. 8 and 9 show the experimental results of dropped call rate and spectral efficiency versus traffic load within (R $2R$ $16R$ $32R$ $64R$) = (10% 30% 30% 20% 10%) which confirmed significant improvement over the fixed code assignment scheme. Fig. 9 depicts the improvement of spectral efficiency, which varied from approximately 2.5% for a traffic load of 150 to approximately 7.5% for a traffic load of 225. Figs. 10 and 11 display the dropped call rate and spectral efficiency versus traffic load regarding served calls that increase the probability of high data rate. The capacity distribution of the calls is ($1R$ $2R$ $16R$ $32R$ $64R$) = (10% 30% 30% 20% 10%). Fig. 10 verifies that while the traffic loads were greater than 175, the dropped call rate of the proposed algorithm is more than the fixed code assignment scheme. That is, the latter scheme increased the dropped call rate of the higher requested data rates (i.e. $32R$ and $64R$). Thus, the lower requested data rates decrease (i.e. $1R$, $2R$ and $16R$). Moreover, this trend shows that our scheme is specifically improved upon the spectral efficiency over the fixed code assignment scheme. Fig. 11 depicts the improvement of spectral efficiency, which varied from approximately 4.2% for traffic load of 150 to approximately 12.8% for traffic load of 225.

5. Conclusions

The WCDMA system supports high-rate bandwidth and variable-rate transmission for various services and applications. Also, it allows the data rate to change during a connection. In this paper, the FDCA algorithm, which assigns code dynamically and, in turn, supports various data rate requirements within the access networks, was proposed. The algorithm is based on the OVSF technique and single-code transmission. Using codewords to regulate all the available codes of a code-tree, the defined binary subtraction can select the best candidate code. If all the descendant codes of the candidate code are available, it can be assigned to the required user. However, if the selected code is blocked, the algorithm can reassign occupied descendant codes to free the selected code. As FDCA algorithm is not required to analyze the topological tree of occupied codes in advance, it is unrestricted in the increasing layers of a code-tree.

To estimate FDCA algorithm's performance, several assumptions have to be made. Experimental results confirm that the number of reassigned codes of the FDCA algorithm is better than Minn and Siu's algorithm although dropped call rate and spectral efficiency is slightly better. Moreover, via an unlimited spreading factor, our scheme has superior spectral efficiency than that without the implementation of DCA scheme. To consider a WCDMA system, the incoming calls are prioritized based on real-time or non-real-time services. For real-time services, the system must assign codes instantly when the calls arrive. In addition, the code assignments for non-real-time calls will be delayed if the system resource is run out. More works need to be done in the future with the consideration of the priority calls.

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