# Multiple OVSF codes Assignment with Crowded Branch First Strategy in WCDMA Systems

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*Abstract:* -In this paper, we consider the environment of using multiple OVSF codes to support a request with any data rate. This paper presents the Crowded Branch First strategy for multiple OVSF codes assignment system. Based on the new strategy and the code word generation method, the system can allocate the appropriated codes to each request under the constraint of assigned code amount, and under the constraint of the maximal resource waste ratio. The results show that using two or three codes is sufficient to achieve high performance.

*Key-Words:* - Code assignment, OVSF code, Wideband CDMA, Resource management.

## 1 Introduction

In recently years, it has become an import issue that how to support users to access the Internet at anytime and anywhere. The major purpose of the third generation (3G) wireless communication networks is the ability to dynamically support a variety of multimedia service at any kinds of environment. Thus, through 3G wireless networks, multiple classes of service can be provided from Internet at anytime and anywhere.

In order to satisfy the QoS of multiple classes of service, 3G system has to provide all of these applications with higher and various transmission rate. Several technologies have been proposed in the 3G standards, and the Universal Mobile Telecommunication System (UMTS) is the major standard of 3G. UMTS proposes employing wideband code division multiple access (WCDMA) technology [1][2]. WCDMA is the key technique of the UMTS, is a multiplexing technique where several independent users share a common channel by modulating preassigned orthogonal code. The receiver then observes the transmitted signal over an additive white Gaussian noise channel.

The WCDMA system adopts the Orthogonal Variable Spreading Factor (OVSF) code as the channelization code to support variable-bit-rate services achieved. The OVSF codes can be represented as a binary code tree, and the code length at each node is equal to the value of its spreading factor. The length of the spreading factor of OVSF codes should be $2^K$ chips, where k is the layer of the node in the OVSF code tree. The bit rates provided by the WCDMA system are always a power of two with respect to the bit rate of the leaf nodes. Thus, the WCDMA system can provide a different bit rate by replacing each bit with a variable spreading factor OVSF code. Consequently, the possible data rates are 1Rbps, 2Rbps, 4Rbps, etc.

However, due to the constraint of possible bit rates, the system will allocate a larger rate of code to some requests. For example, the system should allocate a code with data rate 16R to a request with data rate 9R. This kind of the wasted resource is referred to as internal fragmentation problem [13]. In order to solve the internal fragmentation problem, the environment that each request is assigned multiple OVSF codes should be considered in the design issue of resource management. For example, the system should allocate a code with data rate 8R and a leaf code with data rate 1R to a request with data rate 9R.

Besides the internal fragmentation problem, the code blocking problem is another critical problem of the WCDMA system. The code blocking problem results from the orthogonal property of the OVSF code, which is that the codes in the same layer and the codes in a different layer that do not have an ancestor-descendant relationship are orthogonal. In WCDMA system, all the assigned codes should be mutually orthogonal. While service are arriving and leaving the WCDMA system, the OVSF code tree may become too fragmented, and may hard to find some appropriated OVSF codes to service, even if there are sufficient leaf codes to support its requirement. This problem is called code blocking or external fragmentation problem [13]. Although the code blocking problem can be alleviated when the

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WCDMA system can allocate multiple OVSF codes to a service, the multicode transmission complicates hardware implementation because it must simultaneously control the coding/decoding of multiple transceiver units. Due to the design cost, the amount of transceivers will be limited, and the amount of assigned codes will also be limited.

The code assignment mechanism and the code reassignment mechanism have been proposed to reduce the effects of code blocking. The previous mechanism addresses how to allocate an appropriate code to a service, and the other mechanism addresses how to relocate the codes in the OVSF code trees when the code blocking occurred. The code reassignment mechanism was proposed in [3] that can completely alleviate the code blocking, but will also incur code reassignment costs.

In recently years, there are numerous researches [3]-[9], which widely study in the code assignment and code reassignment problems. Most of these researches are under a single-code-per-request environment [5] to [9]. Some multiple-codes-per -request assignment strategies also had been proposed in the past few years [10]-[14]. A lot of those researches were extended from the single-code-per-request assignment strategy. The major contribution of the paper is to propose a new multi-code assignment strategy. Moreover, in [14], a multi-code word generation method proposed in [14] can derive a code word, whose resources waste ratio will be less than the constraint. The amount codes of the code word are as less as possible, and the system can find the appropriate codes to satisfy the condition of the code word. However, the performance of the code word generation method was not compared with that of the method proposed in [13]. Therefore, in the paper, we will make a detail comparison between the method proposed in [14] and the method proposed in [13].

The rest of this paper is organized as follows: in section 2 we describe our system architecture, and in section 3, we will introduce our multi-code-assignment strategy. The simulation results are described in section 4, while section 5 concludes this paper.

## 2 System Architecture

The information of the current residual codes is very important for the resource management of UMTS. The architecture of the OVSF codes can be represented as a binary tree,. In order to manage the OVSF code trees, the traditional schemes should maintain a binary tree with h layers, where h is $log_2(N)$, and the maintenance complexity is $O(log(N))$. However, based on the management architecture proposed on [9], the maintenance complexity can be reducing to O(1). Moreover, the information of the current residual codes can be easy evaluated by using the cost functions proposed on [9].

As shown in Fig 1, each code in the OVSF code tree can be identified as $C_{sf,bn}$, where *sf* is the spreading factor and its range is from 4 to 512 (downlink) or from 4 to 256 (uplink) for the chip rate of 3.84 Mcps. The second sub-index, *bn*, is the branch number and its range is from 1 to *sf*. Let $S=(s_1, s_2, s_3, s_4, s_5, s_6, s_7,)$ denotes the set of the current residual codes in the system, and $s_i$ denotes the amount of the unused code, whose spreading factor is $2^{i+1}$, where $1 \le i \le 7$ . The value of $s_i$ can be evaluated by using the cost functions proposed on [9]. Let *A* denotes a code word, $A=(a_1,a_2,a_3,a_4,a_5,a_6,a_7,)$, and $a_i$ denotes the required codes whose spreading factor is $2^{i+1}$, where $1 \le i \le 7$ . The actual demand rate of request *j* is $R_j$, and the capacity of code word *A* is $R_a$. The resources waste ratio can be defined as $(R_a\text{-}R_j)/R_a$. Let *f* denotes the maximal resources waste ratio. Assuming that at most n codes can be used by each request, our goal is to derive a code word, whose resources waste ratio should be less *f*. The required codes of the code word should be as less as possible, and the system can find the appropriate codes to satisfy the condition of the code word.

## 3 Multi-Code Assignment Strategy

The multiple codes assignment strategy can be divided into two stages. In the first stage, the code word generation method will consider realistic situation of the current residual codes to get the code word, whose resources waste ratio is less than the constraint, and the required codes are as few as possible. In the second stage, the code assignment strategy will find all the appropriate codes to satisfy the condition of the code word.

### 3.1 Code Word Generation Method

The code word generation had been proposed in [14]. However, for the sake of the integrity of the paper, the detail procedures of code word generation are described as following:

1. Let $R_j' = R_j$, and $i=1$. set $a_i=0$, $1 \le i \le 7$ .
2. If the data rate of spreading factor $2^i$ is less than $R_j'$, then jump to step 3. Else, increase *i* until the data rate of spreading factor $2^i$ is less than $R_j'$, and $i \le 7$. If $i>7$, and resources waste ratio $\le f$ when $c_7=c_7+1$, then update *S* and jump to step 6. Else, jump to step 7.

3. If $s_i>0$, then $R_j' = R_j'$-(*data rate of spreading factor* $2^i$), $a_i=a_i+1$, and $s_i = s_i-1$. Update S.
4. If $R_j'>0$, and the amount of the codes of the code word is less than *n*, increase *i* and return to step 2. Else If $R_j=0$, jump to step 6.
5. $a_i=a_i-1$, and $s_i = s_i+1$. Decrease *i*. If $s_{i-1}>0$, and resources waste ratio $\leq f$ when $a_{i-1}=a_{i-1}+1$, Update *S* and jump to step 6. Else, jump to step 7.
6. If there is a requirement with $a_k>1$ and $s_{k-1}>0$, then $a_k=a_k-2$ and $s_{k-1}=s_{k-1}-1$ and update *S*. Allocates the codes to satisfy the condition of the code word *C*.
7. The system cannot find the appropriate code word under the assumption that at most *n* codes can be used by each request, and under the constraint of maximal resources waste ratio *f*. The request *j* should be blocked.

### 3.2 Code Assignment Strategy

The major function of the code assignment strategy is to select the appropriated code based upon the requirement of the code word which is generated from the code word generation method. The single-code-per-request assignment strategies proposed in the [5]-[9] can also be adopted is the stage.

In this paper, we introduce a new code assignment strategy for the environment of multiple-code-per-request assignment. The new code assignment strategy is referred to as the crowded branch first strategy. The crowded branch first strategy will select the branch which has enough free codes to satisfy the requirement of the code word. The branch with the larger layer number will be picked to accommodate the requirement of the code word. When there are ties, we will select the branch with less free capacity (i,e., more crowded). If so, we will follow the leftmost rule to pick the branch on the left-hand side. It is very obviously that the crowded first strategy is a special case of the crowded branch first strategy, when the crowded branch first strategy works on the environment of the single-code-per-request assignment.

## 4 Simulation results

In this section, we implement a simulator to evaluate the performance of the proposed code generation method in the above sections. According to UMTS standard [1][2], the maximal spreading factor of the simulation is 256. New requests arrive in a Poisson distribution with mean arrival rate $\lambda$ (requests/unit time), and the data rate of each request is between 1R to 16R. The request duration is exponentially distributed, and the mean value is 1 unit of time. The maximal spreading factor is 256, and the traffic pattern can be denoted as the ratio of the arrival rate of (1R:2R:3R:4R:5R:6R:7R:8R:9R:10R:11R:12R:13R:14R:15R:16R). To ensure confidence results, each simulation will run with more than one million incoming requests. In the following, we make observations on the impact of the different code word generation methods, on the impact of constraint of amount of allocated code, and on the impact of the constraint of the maximal resources waste ratio.

Here, we are interested in two performance metrics: the resource utilization, the code blocking probability. The definition of resource utilization is proposed in [7], and the code blocking probability is defined as [7].

$$\textit{code blocking probability} = \frac{\sum_{k=1}^{K} \lambda_k B_k}{\sum_{k=1}^{K} \lambda_k}$$

where $\lambda_k$, and $B_k$ are the arrival rate, and code blocking probability of requests with data rate *kR*, respectively.

The line denoted by *#n* means that the constraint of assigned code number of this strategy is *n*. The line denoted by *#n+old* means that the results obtained form the code word generation method proposed in [14], and the others are obtained form the code word generation method proposed in [13].

Fig. 2 shows the resource utilization at different arrival rates under different assigned code constraint and different code word generation methods. From the results, we can found that the resource utilization slightly improved between the code word generation method proposed in [14] and the code word generation method proposed in [13], when the assigned code constraint is 2. The resource utilization improves significantly when n is increased from 2 to 3. Less significant improvement can be obtained when increasing n to 4, and after $n \geq 5$, there is very little benefit.

Fig. 3 shows the probability of code blocking at different arrival rates under different assigned code constraint and different code word generation methods. From the results, we observe that the code blocking slightly improved between the code word generation method proposed in [14] and the code word generation method proposed in [13], when the assigned code constraint is 2. The code blocking improves significantly when n is increased from 2 to 3. Less significant improvement can be obtained when increasing n to 4, and after $n \geq 5$, there is very little benefit. From the results shown in Fig. 2, Fig. 3 and Table 1, we can say that the performance obtained by the method proposed in [14] are out perform that obtained by the by the method proposed in [13].

Fig 4(a)-(d) show the resource utilization at different arrival rates under different assigned code constraint and different resources waste ratio constraint, and Fig 5(a)-(d) show the code blocking probability at different arrival rates under different assigned code constraint and different resources waste ratio constraint. From these results, we observe that the resource utilization improve significantly when n is increased from 1 to 2. Less significant improvement can be obtained when increasing n to 3, and after $n \geq 4$ there is very little benefit.

Since the system complexity and the design cost will be increased when the multiple transceivers are involved in a UE, an n of 2 or 3 will be quite cost effective. Moreover, the resource utilization is also significantly improved when the resource waste ratio increased from 0% to 20%. Less significant improvement can be obtained when the resource waste ratio $\geq$ 40%.

## 5 Conclusion

In this paper, we have proposed a new multi-code assignment strategy for multiple OVSF codes assignment system. Based on the code word generation method propose in [14], the best code word can be found. According to the code word and using the crowded branch first strategy, the system can allocate the appropriated codes to each request with the constraint of assigned code amount, and under the constraint of the maximal resource waste ratio. From the simulation results shown in section IV, we observed that using two or three codes is sufficient to achieve high performance, and the performance obtained by the method proposed in [14] are out perform that obtained by the by the method proposed in [13].

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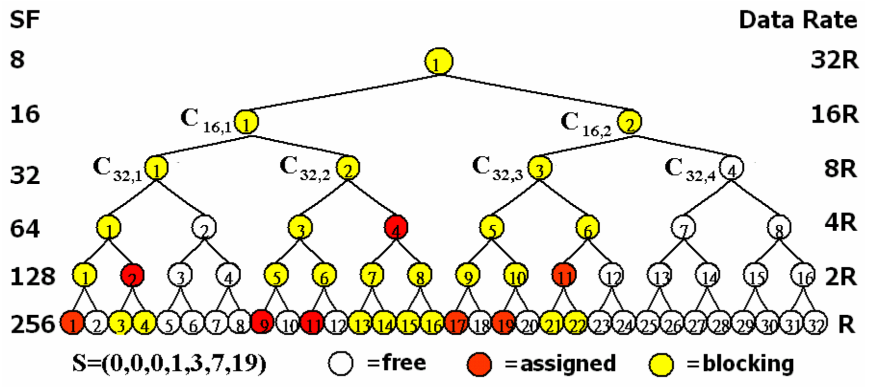


Fig. 1: System structure

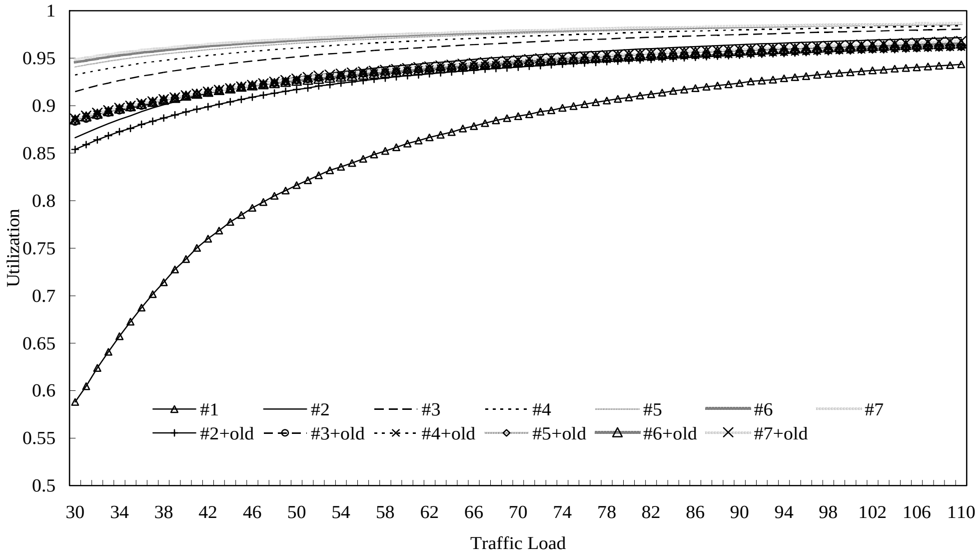


Fig. 2: Resource Utilization Obtained by Different Code Word Generation Methods

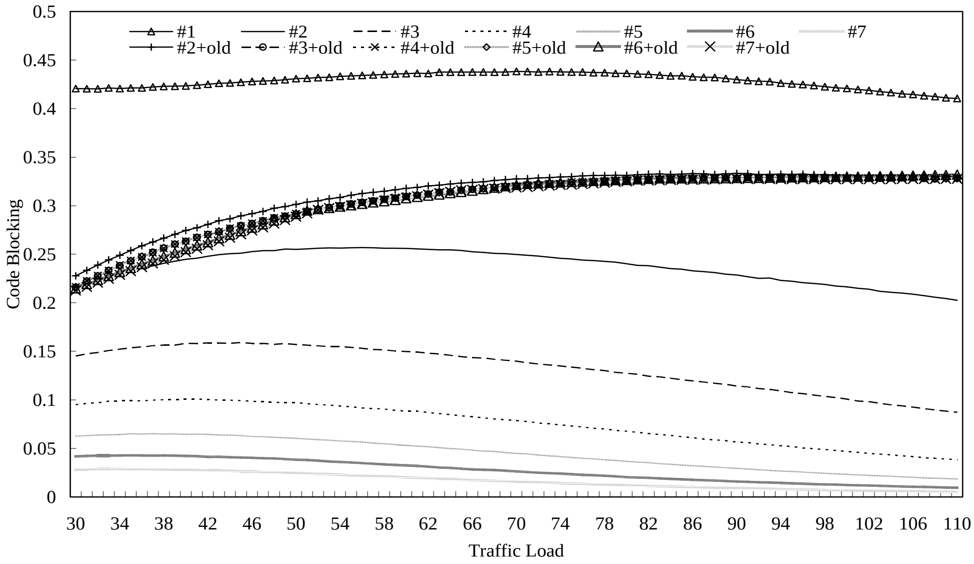
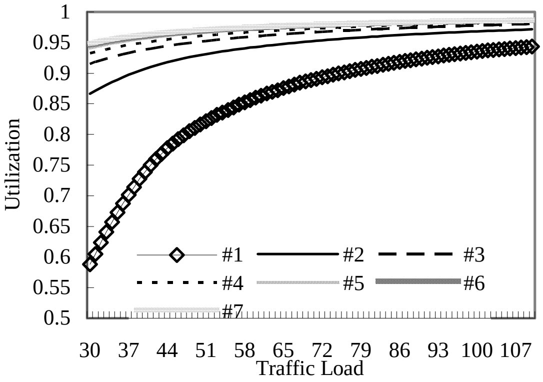


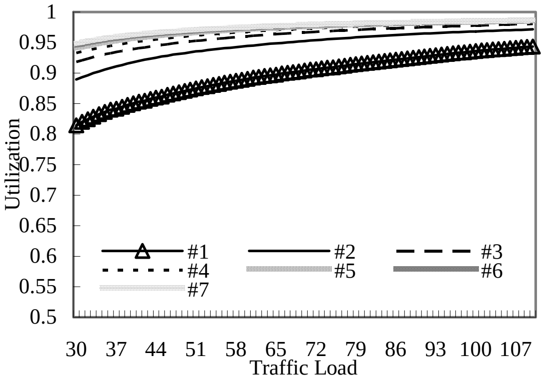
Fig. 3: Code Blocking Obtained by Different Code Word Generation Methods

Table 1 The Average Improvement Percentage of Resource Utilization (compared with #1)

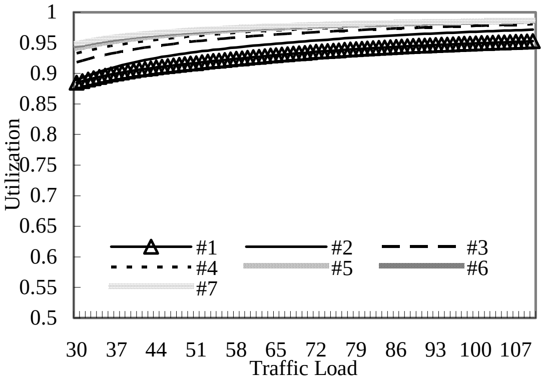
| # codes | #2 | #3 | #4 | #5 | #6 | #7 |
|---|---|---|---|---|---|---|
| [14] | 1.070955 | 1.087187 | 1.094312 | 1.0980418 | 1.100209 | 1.101509 |
| [13] | 1.058076 | 1.062127 | 1.062104 | 1.0620974 | 1.06365 | 1.066636 |



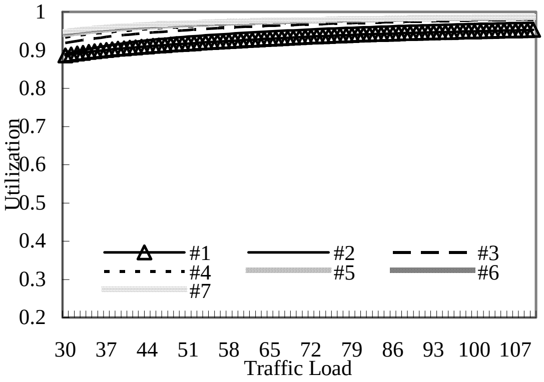
(a) 0%



(b) 20%

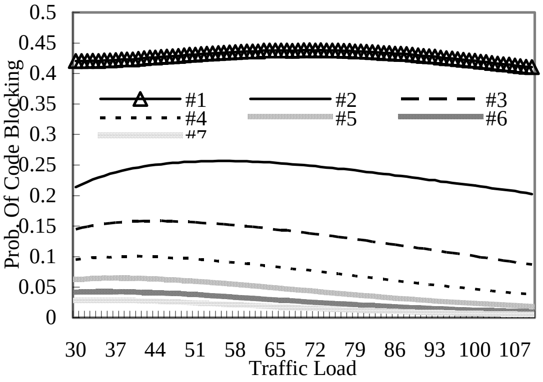


(c) 40%



(d) 60%

Fig. 4 Utilization



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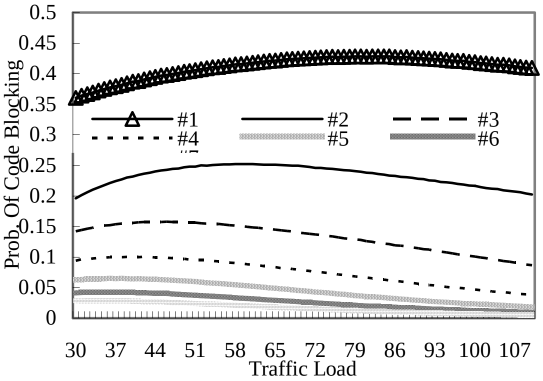

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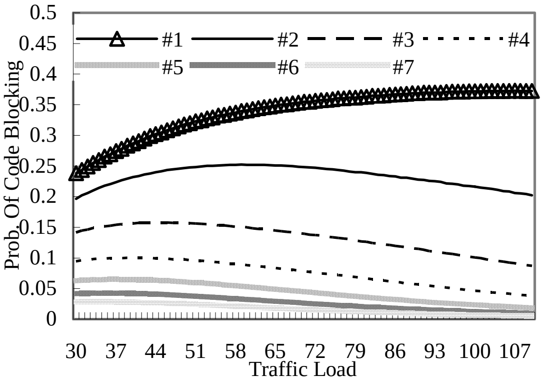
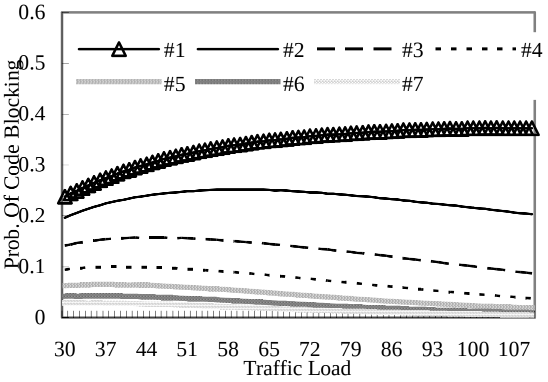


(c) 40%



(d) 60%

Fig.5 Probability of Code Blocking