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Efficient OVSF code assignment strategy in UMTS with Multiple Codes

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Abstract: - In order to provide variable data rates in a flexible manner to support applications with different bandwidth requirements, the orthogonal variable spreading factor (OVSF) codes, adopted by the third-generation partnership project technical specifications, are used as channelization codes. This paper considers the environment of using multiple OVSF codes to support a request with any data rate, and presents a fast and efficient code word generation method for multiple OVSF codes assignment system. Based on our code word generation method, the best code word is found, and the system allocates the appropriated codes to each request under the constraints of an assigned code amount, and a maximal resource waste ratio. The computational complexity of the code word generation method is bounded by the amount of the assigned OVSF code, and by the layers of the OVSF code tree. The results show that using two or three codes is sufficient to achieve a high level of performance.

Key-Words: - code assignment, OVSF code, wideband CDMA, resource management.

1 Introduction

In recent years, the volume of wireless communication has grown exponentially due to the rapid and continual development of new technology. As a result, how to support users with accessing the internet anytime and anywhere has become an import issue.. The key feature of the third generation (3G) wireless communication networks is their ability to dynamically support a variety of multimedia services including data, audio, and video environments. Thus 3G networks allow users access to multiple classes of internet service at anytime and from anywhere.

In order to satisfy the requirements of multiple classes of service, the 3G system has to provide all of these applications with various transmission rates and with higher and different quality of service (QoS) requirements. Several technologies have been proposed in the 3G standards, but the Universal Mobile Telecommunication System (UMTS) is the main 3G. standard. The UMTS system proposes to employ wideband code division multiple access (WCDMA) technology [1][2], supporting variable-rate services achieved by using the Orthogonal Variable Spreading Factor (OVSF) code as the channelization code.

The architecture of the OVSF codes can be represented as a binary code tree, with the code length at each node being equal to the value of its spreading factor. In the UMTS the length of the spreading factor should be 2^K chips, where k is the layer of the node in the OVSF code tree. Thus the data rates are always a power of two with respect to the data rate of the leaf nodes, and the leaf node has the minimum data rate, which is denoted by 1R bps. Consequently, the UMTS system provides a different data rate by replacing each bit with a variable length chip code. Although the OVSF can support higher and variable data rates with a single code using one transceiver, the system will allocate a larger rate of code to some requests due to the constraint of the value of the spreading factor. For example, the system will allocate a code with data rate 16R to a request with data rate 9R. In order to reduce the resource waste ratio, an environment in which each request is assigned multiple OVSF codes should be considered in the design criteria 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.

Moreover, according to the standard, the codes in the same layer and the codes in a different layer that do not have an ancestor-descendant relationship, are orthogonal. All the codes assigned to the requests shall be mutually orthogonal. Due to the orthogonal property of the OVSF code and the single code constraint, the system may not be able to support a request with a single code, even though the system has enough leaf codes to support this requirement. This problem is referred to as code blocking. Although the problem of code blocking can be alleviated when the system is able to allocate multiple OVSF codes to a request, the system

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complexity and the design cost will be increased when multiple transceivers are involved in user equipment. Thus, due to the system complexity and the associated design cost, the number of codes assigned to a request will be limited, and the problem of code blocking cannot be completely alleviated.

Two important strategies have been proposed to reduce the effects of code blocking. They are the code assignment scheme, which tells us how to allocate an appropriate code to a request, and the code reassignment scheme which tells us how to relocate the codes in the OVSF code trees when code blocking occurs. The code reassignment mechanism proposed in [3] can completely alleviate code blocking, but will incur code reassignment costs.

There is much literature available [3]-[13], that is focused on code assignment and code reassignment problems. Most of these studies are under a single-code-per-request environment [5]-[12]. For a multiple-code-per-request environment there is scant literature available.. Although the single-code researches could be extended, there are some problems that need to be studied, such as the amount of codes to be assigned to a request, the sequence of the code assignment, and the relationship between the allocated codes. In this paper, we address the multi-code assignment strategy in the forward link of the UMTS system. Our multi-code assignment strategy is designed based on the single-code assignment and reassignment strategies proposed in [10]-[12]. The major goal of our multi-code assignment strategy is to derive a code word, whose resources waste ratio is less than the constraint. The required codes of the code word should be as few as possible, and the system must be able to find the appropriate codes to satisfy the condition of the code word.

The rest of this paper is organized as follows. In section 2 we describe our code word generation method. The simulation results are described in section 3, and finally we draw our conclusion in section 4.

2 Code Word Generation Method

The information of the current residual codes is very important for the resource management of the 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 in [10]-[12], the maintenance complexity can be reduced to O(1). Moreover, the information of the current residual codes can be easily evaluated by using the cost functions proposed in [10]-[12].

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 $S=(s_1, s_2, s_3, s_4, s_5, s_6, s_7,)$ denote 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 [10]-[12]. Let *A* denote 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 $(R_a-R_j)/R_a$. Let *f* denote 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 with a resources waste ratio that is less than *f*. The required codes of the code word should be as few as possible, and the system can find the appropriate codes to satisfy the condition of the code word.

The detailed procedure of the code word generation is described as follows:

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 the 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 $R_j' = R_j' - (\text{data rate of spreading factor } 2^i)$, $a_i=a_i+1$, and $s_i = s_i-1$. Update S.
4. If $R_j'>0$, and the amount of the codes of the code word < *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 $\le f$ 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 *A*.
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.

In this paper, we have adopted the crowdedgroup first strategy proposed in [10]-[12] to select the appropriate code. The system will allocate the code by increasing order of the spreading factor. For example, let us consider the code tree in Figure 1, *S=(0,0,0,1,3,7,19)*, *f=20%*, and *n=2*. Suppose a request with data rate 6R arrives, the code word of this request is *(0,0,0,0,1,1,0)*. Then the system will allocate code $C_{64,2}$, and code $C_{128,12}$, to the request. Or suppose that a request with data rate 7R arrives, the code word of this request is *(0,0,0,1,0,0,0)*. The system will allocate code $C_{32,4}$ to the request. Let's suppose *n=3*, the code word of the request with data rate 7R is *(0,0,0,0,1,1,1)*, and the system will allocate the code $C_{64,2}$, the code $C_{128,12}$, and the code $C_{256,2}$, to the request.

However, suppose *f=10%* and a request with data rate 7R arrives, then the system cannot find the appropriate code to satisfy the request, and the request with data rate 7R will be blocked. It is evident that when *f=100%* and all the s_i is ∞, the code word generated by our method is the same as that generated by the method proposed in [13].

It is evident that the required codes of the code word generated by our method are as few as possible, and the system can find the appropriate codes to satisfy the condition of the code word. The computation complexity of the code word generation method is bounded by the amount of the assigned OVSF code, and by the layers of the OVSF code tree.

3 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 the UMTS standard [1,9], the maximal spreading factor of the simulation is 256. New requests arrive in a Poisson distribution with mean arrival rate λ (requests/unit time), and the data rate of each request is between 1R to16R. The request duration is exponentially distributed with a mean value of 1 unit of time. The traffic pattern can be denoted as the ratio of the arrival rate of (1R:2R:3R:4R:5R:6R:7R:8R) or (1R:2R:3R:4R:5R:6R:7R:8R:9R:10R:11R:12R:13R:14R:15R:16R). To ensure stable results, each simulation will run with at least 1,000,000 incoming requests. In the following we make observations on the impact of the constraint on the amount of allocated code, and on the impact of the constraint of the maximal resources waste ratio.

In this study we are interested in three performance metrics: the resource utilization, the code blocking probability, and the weighted code blocking. The definition of resource utilization is proposed in [8], and the code blocking probability is defined as [8].

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

where λ_k, and B_k are the arrival rate, and the code blocking probability of requests with data rate *kR*, respectively. However, this metric is unfair for the requests with a high data rate [11][12]. Thus, the weighted code blocking proposed in [11][12] is introduced in this paper. The weighted code blocking is defined as follows:

$$\textit{weighted code blocking} = \sum_{k=1}^{K} r_k \lambda_k B_k \Big/ \sum_{k=1}^{K} r_k \lambda_k ,$$

where r_k is the reward of the requests with data rate *kR*. It is evident that the strategy with the lower weighted code blocking can utilize the OVSF codes in the UMTS system more efficiently. In our simulation, the reward is equal to the data rate.

Two kinds of traffic pattern are implemented in the simulator. They are (1:1:1:1:1:1:1:1) and (1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1). The line denoted by *#n* means that the constraint of the assigned code number of this strategy is *n*. Figures 2(a)-(b) and Figures 3(a)-(b) show the resource utilization at different arrival rates under different assigned code constraint and different resources waste ratio constraints with max SF=256. From these results, we observe that the resource utilization improves significantly when n is increased from 1 to 2. A 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 multiple transceivers are involved in user equipment, an n of 2 or 3 will be quite cost effective. Moreover, the resource utilization is also significantly improved when the resource waste ratio is increased from 0% to 40%. A less significant improvement can be obtained when the resource waste ratio>40%.

There is an interesting result in Figure 2(b). The resource utilization of #2 is higher than that of #n, where $n \geq 3$, when the resource waste ratio $\geq$ 40%, and the resource utilization of #1 is higher than that of #n, where $n \geq 2$, when the resource waste ratio >40%. This is because the metric of the resource utilization is evaluated by allocating resource to each request. Due to the fact that the maximal resource waste ratio is increased, the system will allocate increased resources to a request. In fact, the waste ratio of the resource utilization of #1 is about 10%, and the waste ratio of the resource utilization of #2 is about 2%.

Figures 4(a)-(b) and Figures 5(a)-(b) show the code blocking probability at different arrival rates under different assigned code constraint and different resources waste ratio constraint with max SF=256. It is evident that the code blocking probability is also significantly improved when n is increased from 1 to 2, and is less significantly improved when n is increased to 3. When $n \geq 4$, then there is very little benefit. The code blocking probability is less significantly improved when the resource waste ratio is increased from 0% to 40%, but is significantly improved when the resource waste ratio>40%.

Figures 6(a)-(b) and Figures 7(a)-(b) show the weight code blocking at different arrival rates under a different assigned code constraint, and under different resources waste ratio constraint with max SF=256. These results also show that the weight code blocking is significantly improved when n is increased from 1 to 2, and when the resource waste ratio is 40%. Thus, the system performance can be significantly improved when n is 2 and the resource waste ratio=40%. When the assigned code constraint≥ 3, then the system performance has less of an improvement when the resource waste ratio is increased.

4 Conclusion

In this paper, we have proposed a new code word generation method for the multiple OVSF codes assignment system. Based on this code word generation method, the optimal code word can be found, and the system can allocate the appropriate codes to each request with the constraint of the assigned code amount, and under the constraint of the maximal resource waste ratio. The computational complexity of the code word generation method is bounded by the amount of the assigned OVSF code, and by the layers of the OVSF code tree. From the simulation results shown in section 3, it is evident that using two or three codes is sufficient to achieve a good performance.

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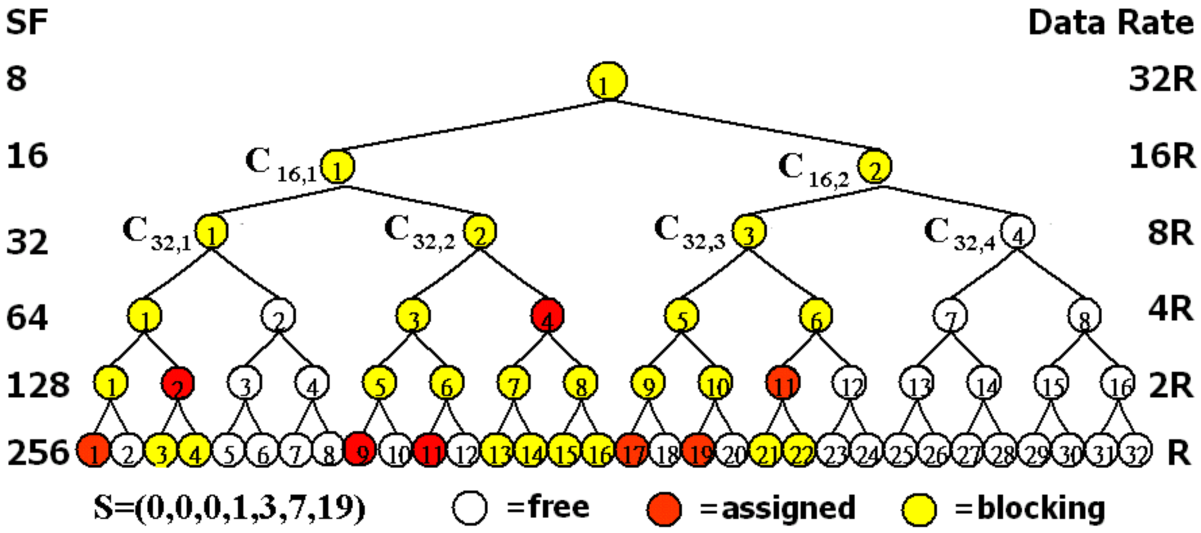
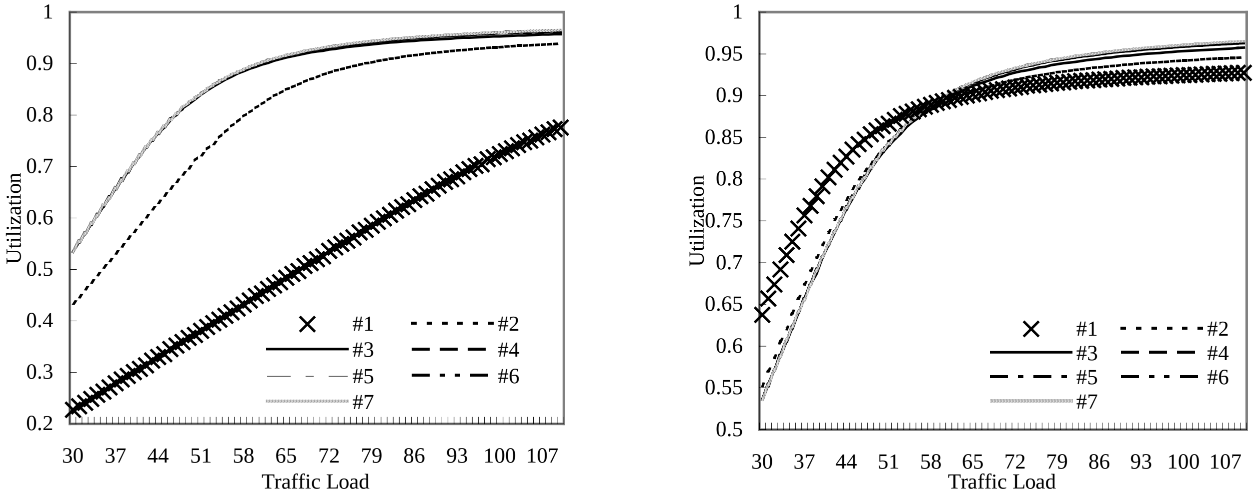


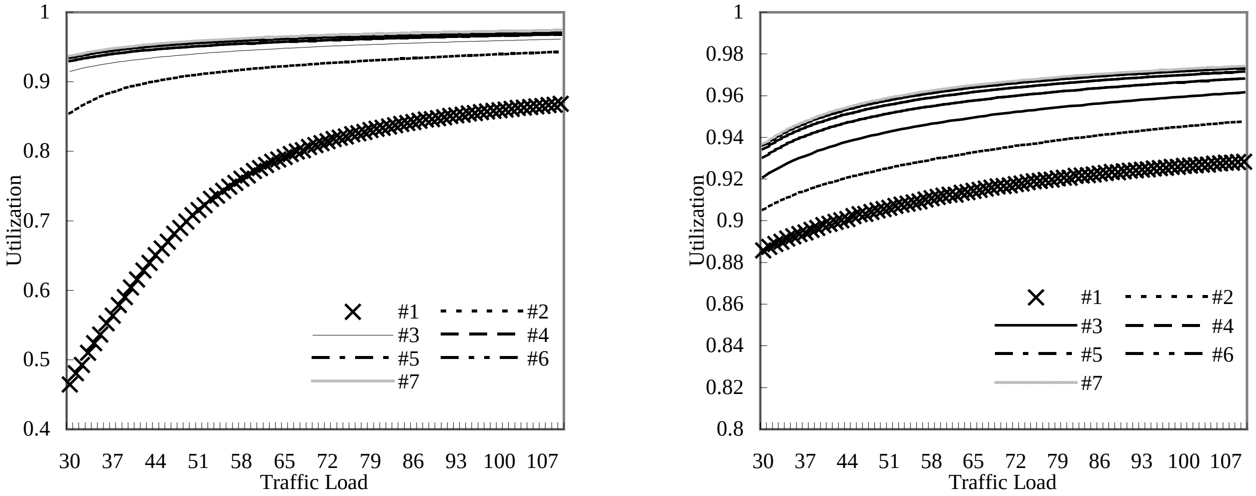
Fig. 1: System structure



(a) *f*=0%

(b) *f*=40%

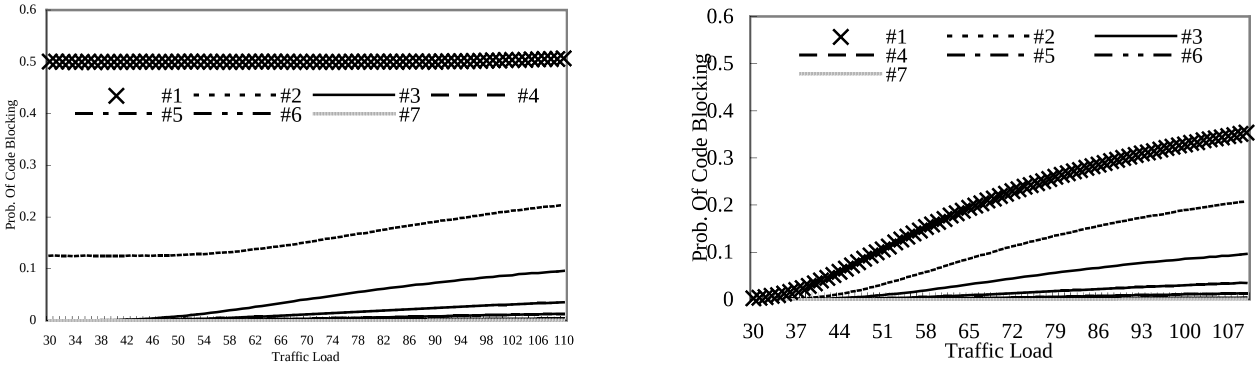
Fig. 2: The resource utilization: traffic pattern=(1:1:1:1:1:1:1:1)



(a) *f*=0%

(b) *f*=40%

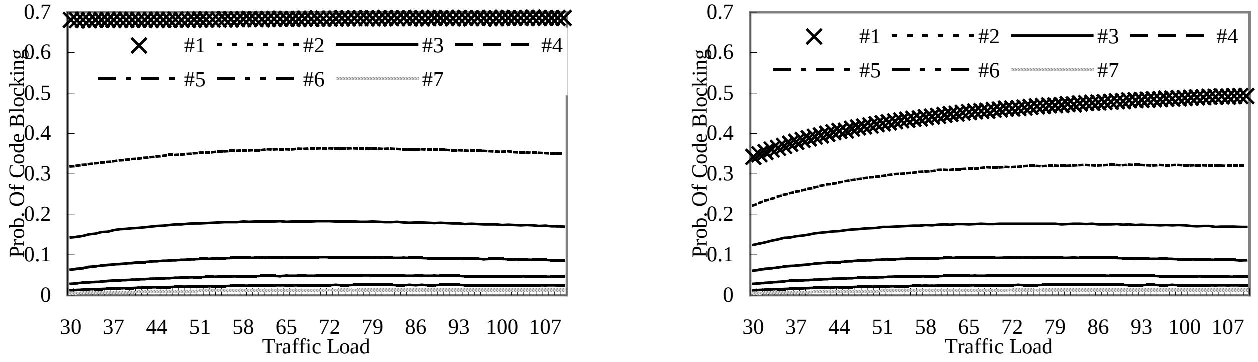
Fig. 3: The resource utilization: traffic pattern=(1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1)



(a) *f*=0%

(b) *f*=40%

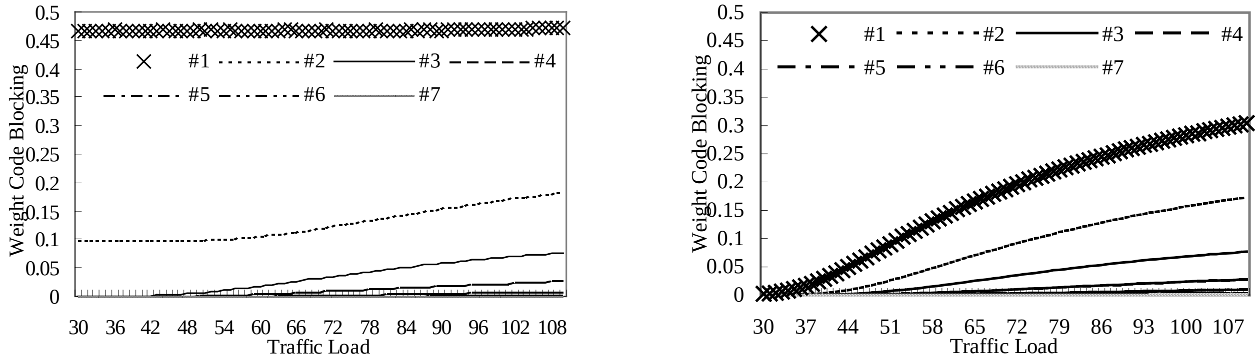
Fig. 4: The code blocking probability: traffic pattern=(1:1:1:1:1:1:1:1)



(a) *f*=0%

(b) *f*=40%

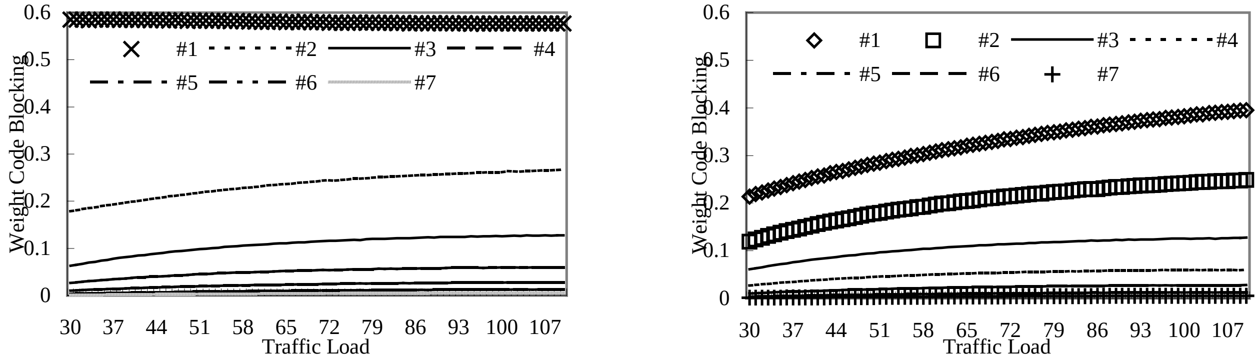
Fig. 5: The code blocking probability: traffic pattern=(1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1)



(a) *f*=0%

(b) *f*=40%

Fig. 6: The weight code blocking: traffic pattern=(1:1:1:1:1:1:1:1)



(a) *f*=0%

(b) *f*=40%

Fig. 7: The weight code blocking: traffic pattern=(1:1:1:1:1:1:1:1:1:1:1:1:1:1:1:1)