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Efficient Multiple OVSF code assignment strategy in UMTS

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Abstract: - The key feature of the third generation (3G) wireless communication networks is the ability to dynamically support a variety of multimedia service. In order to satisfy the requirements of multimedia services with variable data rates, the orthogonal variable spreading factor (OVSF) codes, adopted by the third-generation partnership project technical specifications, are used as channelization codes. This paper presents an efficient code assignment strategy under the assumption of using multiple OVSF codes to support a request with any data rate. We also propose a fast and efficient code word generation method for multiple codes assignment system. Our code word generation method can find the best code word under the constraint of an assigned code amount, and under the constraint of 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. From the simulation results, we 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

Due to the rapid development of new wireless communication technology, the volume of wireless communication has grown exponentially in recent years. It is expected that how to support users with accessing the internet anytime and anywhere has become an import issue within decades. The key feature of the third generation (3G) wireless communication networks is the ability to support a variety of multimedia services including data, audio, and video environments, at anytime and from anywhere.

The 3G system has to provide all of these applications with various transmission rates and with higher and different quality of service (QoS) requirements, in order to satisfy the requirements of multiple classes of service. 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

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alleviated when the system is able to allocate multiple OVSF codes to a request, the system 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]-[20], that is focused on code assignment and code reassignment problems. Most of these studies are under a single-code-per-request environment [5] to [14]. 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 [11]-[13]. 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 look at some of the reviews regarding the code management strategies, and section 3 we describe our code word generation method. The simulation results are described in section 4, and finally we draw our conclusion in section 5.

2 Related works

Many single-code-per-request assignment strategies have been proposed in the past few years, including the Left-most strategy (LM)[4], Compact Index strategy (CI)[5][6], Regional division assignment strategy [7], Crowded-First strategy (CF)[8][9], weight crowded- first strategy [10], and Crowded-Group First strategy (CGF) [11][12][13]. These strategies are all focused on reducing code blocking probability and the time complexity. The left-most strategy allocates the code placed in the code tree as much as possible to the left to the request. Chen et al. proposed an improvement on the Left-most strategy [14]. The strategy allocates codes placed on the left-hand side of the code tree to the requests with low data rate, and allocates codes placed on the right-hand side to the requests with a high data rate. When each request ends its service, the request occupying the code on the rightmost side, is relocated to the code just released. The main drawback of these strategies is that it may perform a large number of unnecessary code reassignments.

The compact index strategy tries to reduce the probability of code blocking without the reassignment strategy. It tries to allocate the code in the crowded branch to the request. It selects the codes based on the value of the compact index, which represents the positional relationship of a code in the code tree. The code in the crowded branch has a smaller compact index value. Thus, the code with the smaller compact index is preferred for allocation. The computation complexity of the strategy is *O(NlogN)*.

The crowded-first strategy improves the computation complexity by solving the code assignment problem. It always selects the code whose immediate upper-layer sub-branch will have the least free capacity after the allocation. The basic idea of this strategy is similar to that of the compact index strategy, but the computation complexity of the crowded-first strategy is *O(N)*. However, due to the fact that this strategy may require a recursive search from the level of the request’s rate up to the root node, its main drawback is the large amount of decision time.

The idea of the weight crowded-first strategy is quite similar to the crowded-first strategy. The difference is that it selects the code with the minimal number codes that will be blocked after the candidate code is assigned. Since the number of the lower layer codes to be blocked is the same for every candidate codes, the difference will be in the number of the upper layer codes to be blocked. The computation complexity of this strategy is slightly better than that of the crowded-first strategy. However, the code blocking probability of this strategy is worse than that of the crowded-first strategy.

In order to improve the computation complexity, we proposed the crowded-group first strategy. The main idea behind our strategy is to make the OVSF code tree as compact as possible in order to be able to accept more new requests At first glance it looks very similar to the compact index strategy and the crowded-first strategy. However, in order to reduce the decision time, the cost functions and the concept of the hierarchical logical groups structure were introduced. Based on the cost functions, the computation complexity can be improved to $O(log^2(N))$.

There is a serious problem in those strategies proposed in [4]-[13]. When the traffic load increases, a request with a higher data rate will have difficulty obtaining an appropriate code in those strategies. Those strategies cannot provide a good acceptance rate for a request with a higher data rate. Assarut el al. proposed the regional division assignment strategy [7], which provides a good acceptance rate for the request with any data rate. The code tree is divided into several regions for each rate. In order to efficiently assign codes, each region is to serve one specific data rate service. When a region uses up its capacity, the codes of other regions can be borrowed. The regional division ratio can be obtained by the request arrival rates, and it greatly impacts upon the system performance. The major problem of the regional division assignment strategy is that the patterns of request arrival rates change dynamically, and the optimal partition proportion becomes hard to find. Moreover, due to the borrowing action, the code tree may become fragmented. The time complexity and the maintenance complexity are O(N).

We also proposed the Markov decision process (MDP) [15] based code assignment strategy in order to improve the acceptance rate for the request with any data rate. Our strategy can be divided into two aspects. First, the MDP code assignment approach represents each level state and the complete OVSF code tree state as a Markov Decision Process. Second, the MDP call admission control mechanism is proposed to increase the system reward while reducing the blocking. The numerical results indicate that the proposed MDP approach yields a better system performance.

Some multiple-codes-per-request assignment strategies have been proposed in the past few years [16]-[20]. [16], [17], and [18] proposed a mechanism which can find the available codes, called a code word, and assign these codes to the request. At first, those strategies will find several code words for a request. The code word with the least codes used should be the preferable choice. Although those strategies are efficient and consider the allocation of multiple codes, what code and what branch should be chosen remains unclear. Moreover, the question of which code word is the best number of OVSF codes to be used is not even considered in those strategies.

Tseng et al. proposed a strategy in [19][20] to find the best number of OVSF codes to be used. The goal of their strategy was to find the code word with the least number of codes and the smallest resources waste ratio under the assumption that at most n codes can be used by each request. They also considered the code selection problem in their strategy. Numerical results show an increase in code tree utilization and a reduction in code blocking probability when using their strategy. Although the code word with the least number of codes can be found by using their strategy, the system may not find the appropriate codes to satisfy the condition of the required code word. This is due to the fact that the code word generation method proposed by their strategy is not based on the practical residual OVSF codes.

According to the time the policy is employed [10][13], the code reassignment strategies can be grouped into proactive policies [4][14], and reactive policies [8]-[10][13]. The proactive policy performs the code reassignment procedure when a request departs, or when a predefined or a periodic timer expires. The main drawback of this approach is the huge amount of unnecessary code reassignments. The reactive policy only performs the code reassignment procedure when a code blocking occurs.

The code reassignment procedure adopted by most of those strategies proposed in [8]-[10][13] was the dynamic code reassignment algorithm (DCA) proposed in [3]. This procedure first selects the reassigned branch based on cost. The cost is defined as the number of requests that need to be relocated if this branch was selected to be deleted. The request is then assigned a code in the selected branch. The code assignment issue is not discussed in this paper. To avoid an exhaustive search, the code pattern search is based on a cost comparison table, which is computed off-line. Also, the code assignment strategy is not considered in this paper.

3 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 [11]-[13], 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 [11]-[13].

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 [11]-[13]. 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 $R_j' = R_j'$*-(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 crowded-group first strategy proposed in [11]-[13] 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 [19].

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.

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 the UMTS standard [1,10], 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 two performance metrics: the resource utilization, and the code blocking probability. The definition of resource utilization is proposed in [7][8], and the code blocking probability is defined as [7][8].

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

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

Two kinds of traffic pattern are implemented in the simulator. They are A:(8:7:6:5:4:3:2:1) and B:(16:15:14:13:12:11:10:9:8:7:6:5:4:3:2:1). The line denoted by *#n* means that the constraint of the assigned code number of this strategy is *n*. Figures 2(a)-(c) and Figures 3(a)-(c) 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 20%. A less significant improvement can be obtained when the resource waste ratio ≥ 40%.

There is an interesting result in Figures 2(b)-(d). The resource utilization of #2 is higher than that of #n, where $n \geq 3$, when the resource waste ratio ≥ 20%, 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)-(d) and Figures 5(a)-(d) 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 20%, but is significantly improved when the resource waste ratio is 40%.

Figures 6(a)-(d) and Figures 7(a)-(d) 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 is 40%. When the assigned code constraint ≥ 3, then the system performance has less of an improvement when the resource waste ratio is increased.

5 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 4, it is evident that using two or three codes is sufficient to achieve a good performance.

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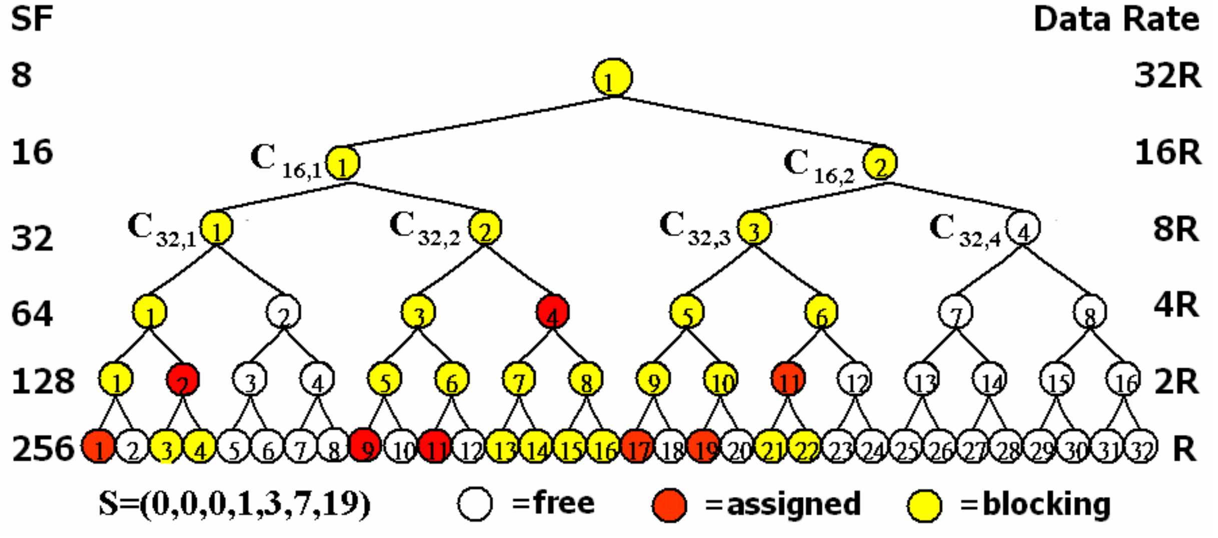
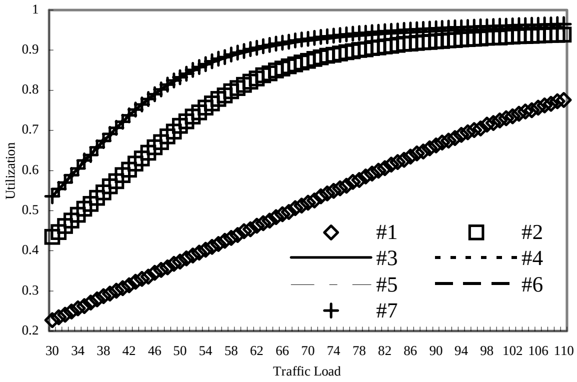


Fig. 1: System structure



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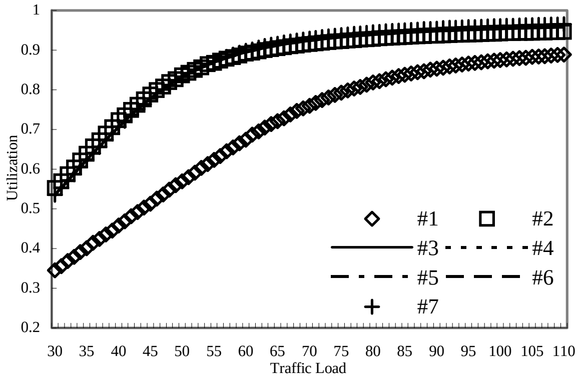

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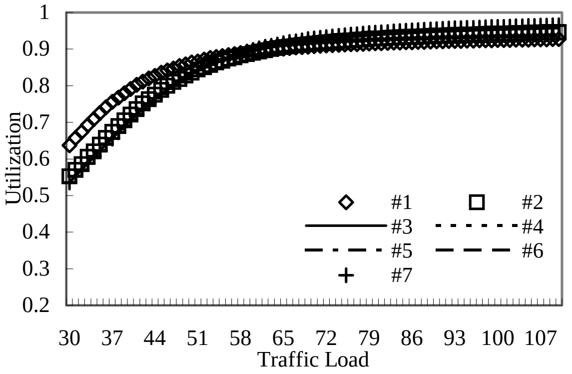

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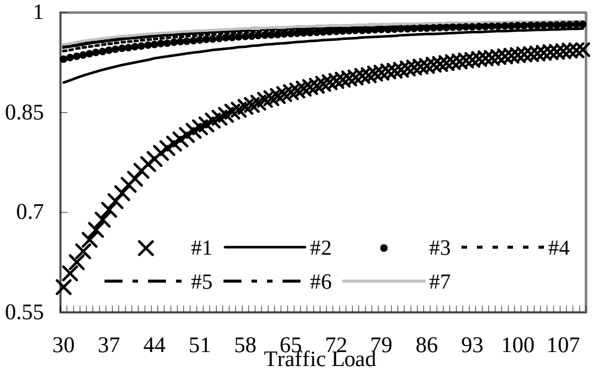
Fig. 2: The resource utilization: traffic pattern=(1:1:1:1:1:1:1:1)



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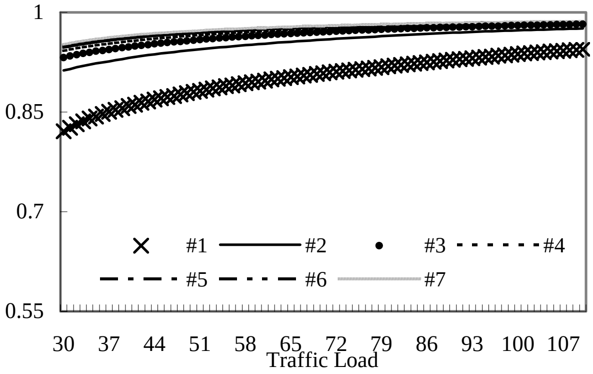

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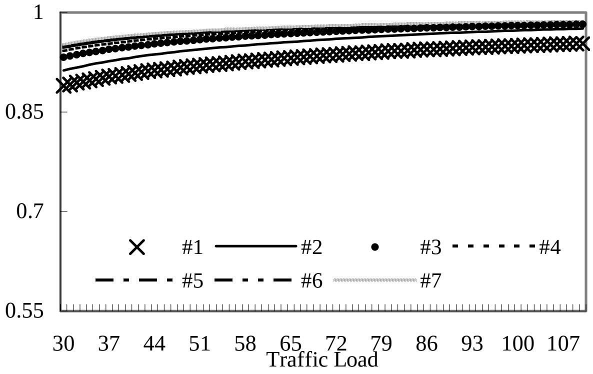
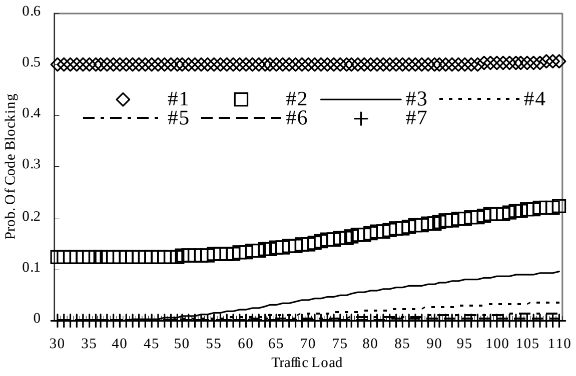


(c) *f*=40%

Fig. 3: The resource utilization: traffic pattern B



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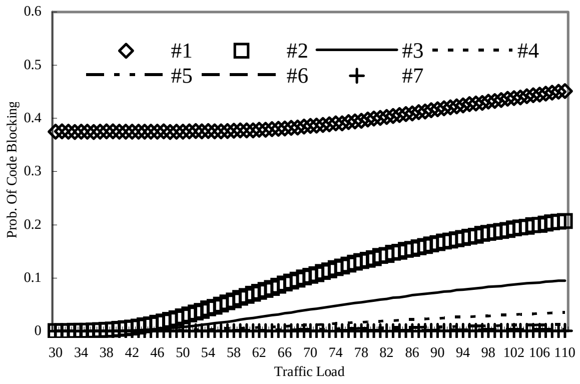

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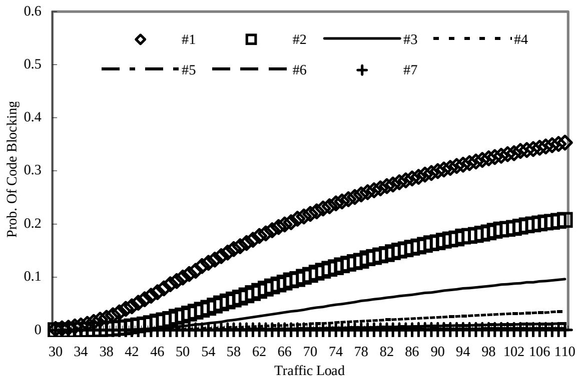
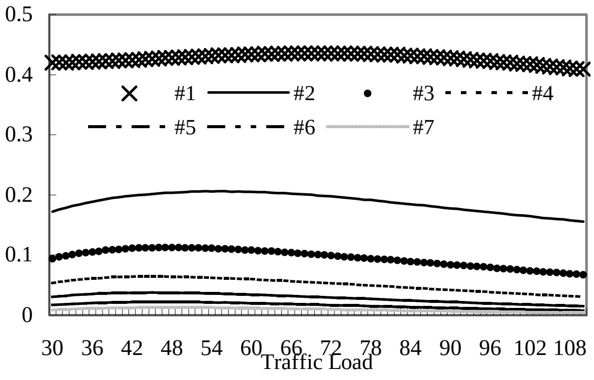
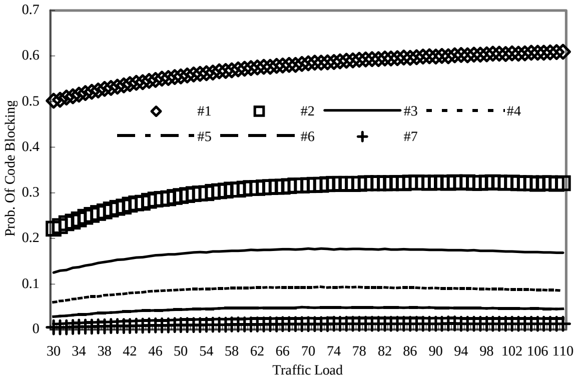


(c) *f*=40%

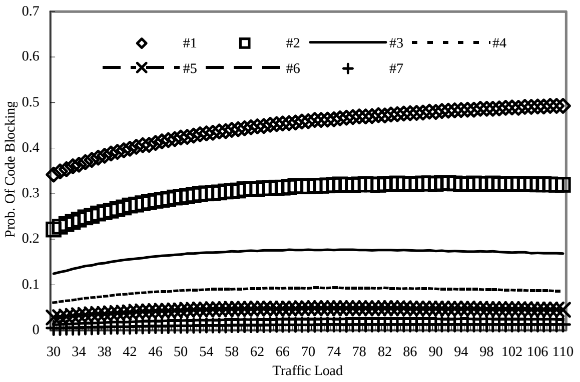
Fig. 4: The code blocking probability: traffic pattern=(1:1:1:1:1:1:1:1)



(a) *f*=0%

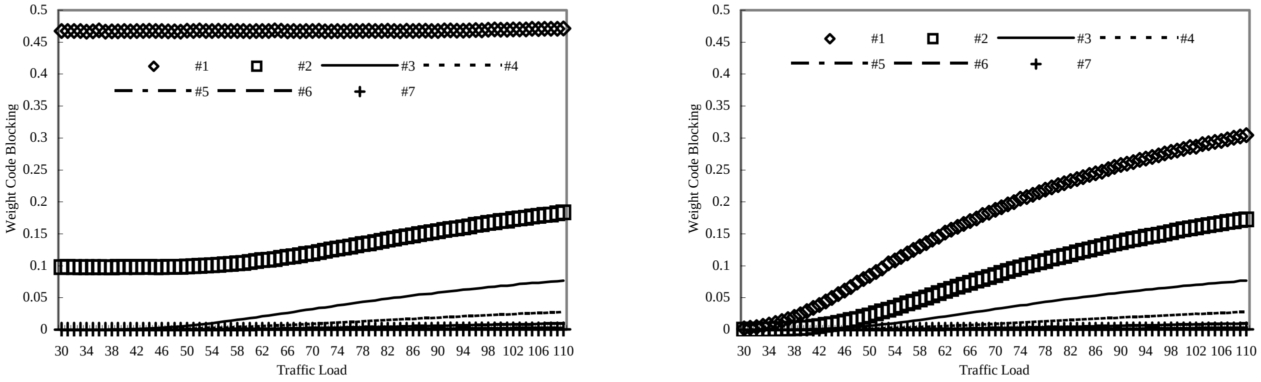


(b) *f*=20%



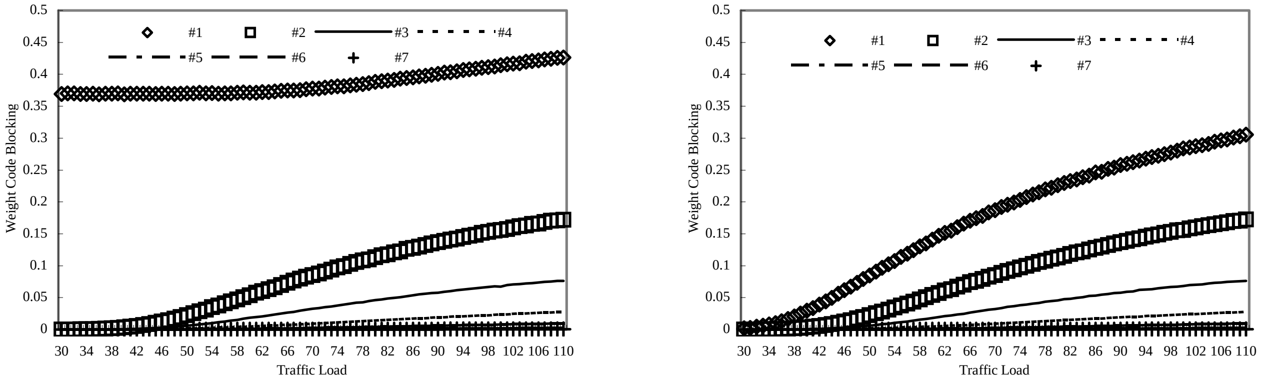
(c) *f*=40%

Fig. 5: The code blocking probability: traffic pattern B



(a) *f*=0%

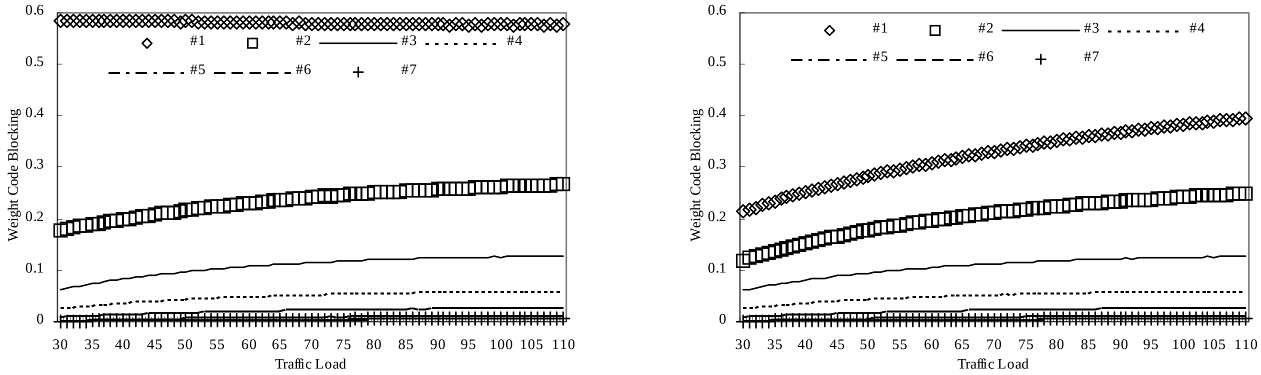
(c) *f*=40%



(b) *f*=20%

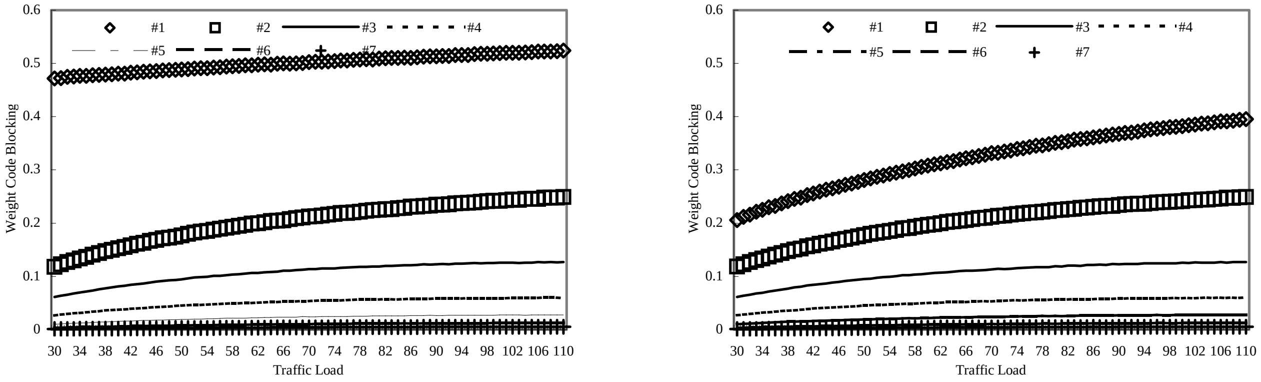
(d) *f*=60%

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



(a) *f*=0%

(c) *f*=40%



(b) *f*=20%

(d) *f*=60%

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