

Modeling and Analysis of Code-based Call Admission Control for QoS Management in W-CDMA Systems

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Efficient resource allocation for multi-class traffic with QoS guarantee is an important issue in integrated multimedia mobile communication networks. In the third generation mobile communication systems, the Orthogonal Variable Spreading Factor (OVSF) codes are used as spreading codes. The use of OVSF codes allows the spreading factors to be changed for variable bit-rate requirements. In this paper, we presented the code-based guard channel schemes and analytical models for QoS management in W-CDMA systems. Compared with traditional channel-based schemes, the proposed schemes and analytical models exactly reflect the restrictions of OVSF code tree characteristics and are suitable for W-CDMA systems. From the illustrations and numerical results, we find that the proposed model is easy to construct and to analyze QoS management schemes in W-CDMA systems. It can also be extended to more complicated multi-class traffic types systems.

Keywords: call admission control, code allocation, guard channel, OVSF, QoS, W-CDMA

1. INTRODUCTION

The next generation wireless communication networks are designed to support integrated multimedia services. The various types of services have different bandwidth demands and performance requirements. To satisfy the different types of requests with quality of service (QoS) guarantee, effective resource allocation has become an important issue in radio resource management [1, 2].

In the literature, several QoS management schemes have been proposed to satisfy the desired requirement of QoS guarantee for each type of services in wireless and mobile communication systems. Guard channel (GC) scheme is a popular scheme which reserves some available channels for prioritized traffic types [3]. For example, in call admission control mechanism, dropping of an ongoing call is less desired than blocking a new call. Thus, handoff calls have high priority than new calls. Many GC schemes have been proposed to reserve some channels for handoff calls to maintain the handoff calls dropping probability under a predefined threshold. In [4], schemes such as new call bounding, cutoff priority and new call thinning schemes that reserve guard channels for prioritized handoff calls are investigated. In [5], an adaptive QoS handoff priority scheme which exploits the ability of multimedia traffic types to adapt and trade off QoS with changes in the amount of bandwidth used.

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In more complicated cases, more than two classes of traffics are considered. For example, in the third generation (3G) wireless communication systems, four classes of traffic types are identified by their delay sensitivity: conversational, streaming, interactive and background classes. Different priorities are assigned according to their class types for channel allocation. In [6], a dual threshold bandwidth reservation scheme (DTBR) exploits a complete sharing approach with multiple thresholds to meet the specific QoS requirements. Multiple classes of data traffic including handoff voice calls, new voice calls and mixed data calls are investigated. In [7], an adaptive measured-based resource allocation scheme for multimedia QoS support which consists of three service classes with different handoff-dropping requirements is presented. In [8], a preemptive priority scheme for an integrated wireless and mobile network divides channels into three independent groups and classifies traffic into four different types. A recursive algorithm is used to determine the minimal number of channels in each channel group to satisfy the QoS requirements. More resource allocation schemes for multiclass traffic with QoS constraints are proposed in [9, 10]. However, the system becomes more complex as the number of the divided classes increases. At the same time, the analytical work becomes more intractable either.

Most of the schemes mentioned above are channel-based, that is, the consideration is focused on channel allocation. However, in the modern communication systems, such as W-CDMA systems, the OVSF codes are used to spread and channelize codes. To keep the orthogonality of the code tree, rigid restrictions exist. A code can be assigned to a new call if and only if no other code on the path from the specified code to the root of the tree or in the subtree below the specified code is assigned. Under these constraints, *code blocking* occurred in which a new call is blocked due to the fragmentation of free codes even though the system has enough capacity. The code blocking probability plays an important role, and deeply influences the system performance evaluation in W-CDMA systems. In [11], the authors first proposed the OVSF codes analytical model to analyses system performance and derived to the time-based code allocation schemes in W-CDMA systems. In this paper, we propose the code-based guard schemes for resource allocation with QoS management in W-CDMA systems. In contrast to the existent channel-based resource allocation schemes, our proposed schemes exactly reflect the restriction of OVSF code tree and can be used in modern wireless communication systems. In addition, we present an OVSF analytical model to evaluate the proposed schemes. The proposed model can be used to construct and analyze QoS management schemes in W-CDMA systems. It can also be extended to multi-class traffic types systems for various applications.

The rest of the paper is organized as follows. In section 2, we give a brief overview of the issues and restrictions in OVSF code allocation in W-CDMA systems. In addition, the basic analytical model is introduced to evaluate system performance. In section 3, we proposed the code-based guard schemes to resource allocation schemes with QoS management. Besides, we propose an OVSF analytical model to evaluate the system performance. In section 4, the numerical experiments are conducted to demonstrate the performance of the system model. Finally, the conclusion remarks are drawn in section 5.

2. ANALYTICAL MODEL

In this section, we have a brief overview of the issues and restrictions in OVSF

code allocation in W-CDMA systems firstly. Based on the restrictions of OVSF codes, a basic OVSF analytical model that reflects the OVSF characteristics is developed to evaluate the system performance of resource allocation schemes.

2.1 Issues in Code Allocation in W-CDMA Systems

In W-CDMA systems, Orthogonal Variable Spreading Factor (OVSF) codes are used to spread and channelize codes [12, 13]. The use of OVSF codes allows the spreading factors to be changed for variable bit rate, such that supporting variable data rate for different requirements. The OVSF-CDMA systems are advantageous to develop the growing demand of multi-class multimedia services with different QoS satisfaction.

The generation of OVSF codes can be represented by a tree structure [14]. Each code in the code tree is denoted as $C_{SF,code\ number}$, where SF indicates the spreading factor and the code number is a sequence number ranging from 1 to SF. The code with a smaller SF value provides a higher data rate. To preserve the orthogonality, some restrictions are posed in code allocation in a code tree. A code can be assigned to a new call if and only if no other code on the path from the specified code to the root of the tree or in the subtree below the specified code is assigned. Under these constraints, code blocking occurred in which a new call is blocked due to the fragmentation of free codes even though the system has enough capacity. In Fig. 1, a case of a code blocking is illustrated. If the data rate for the leaves in the code tree is R , the data rates for $SF = 8, 4, 2, 1$ are $R, 2R, 4R$ and $8R$ respectively. The total capacity is $8R$. Codes $C_{4,1}$, $C_{8,3}$ and $C_{8,5}$ are occupied by existent calls, and the free capacity of the code tree is $4R$. If a new call arrives and requests for data rate $4R$, the call is rejected and causes a code blocking due to the shortness of available free codes even though the free capacity is enough to support.

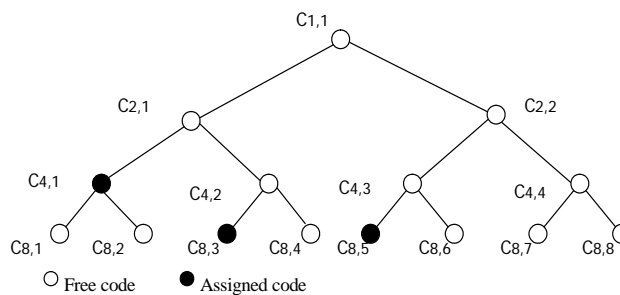


Fig. 1. The case of code blocking.

The effect of code blocking plays an important role, and deeply influences the overall system performance evaluation. Some efficient code allocation schemes are proposed to lower the code blocking probability [11, 15-17]. In [11], the author first proposed the OVSF codes analytical model to analyze system performance and derived to the time-based code allocation schemes. The proposed analytical model can be used to approximate the blocking probability of the OVSF allocation scheme under various load conditions, and can be used to evaluate the system performance of code allocation schemes. We introduce this model in next subsection.

2.2 System Model

For simplicity, we consider a system with two requested classes of data rate, R and $2R$. The analytical technique can be applied to more complicated examples.

Let $Q(N, \lambda_1, \mu_1, \lambda_2, \mu_2)$ denote the system in which N indicates the total capacity of the OVSF code tree; λ_1 and μ_1 indicate the arrival rate and departure rate for calls from class R ; and λ_2 and μ_2 denote the arrival rate and departure rate for calls from class $2R$. We assume that the call arrivals form a Poisson process and the service time follows the negative exponential distribution. Let (x, y) represent a state of the system in which x denotes the number of ongoing calls with data rate R , while y denotes the number of ongoing calls with data rate of $2R$. The process can be modeled as a Markov chain with the following state space:

$$S = \{(x, y) \mid x, y \geq 0, x + 2y \leq N\}. \quad (1)$$

Let $p(x, y)$ be the steady-state probability that there are x calls of data rate R and y calls of data rate $2R$ in the system. Each state (x, y) represents a number of combinations in which some combinations lead to a blocked state upon the arrival of a new call while other combinations do not. The conditional blocking probability of state (x, y) is computed by the number of combinations, which lead to a blocked state upon the arrival of a new call, over the total number of possible combinations. While an incoming call arrives in state (x, y) , two possible situations can be considered:

2.2.1 Case 1: the incoming call requests for data rate R

Upon the arrival of an incoming call requests for data rate R , the call will be blocked only when all capacity is occupied. The blocking appears in the following set of states,

$$S_1 = \{(x, y) \mid x + 2y = N\}. \quad (2)$$

Hence, the conditional blocking probability of state (x, y) upon the arrival of a data rate R is

$$p_{B|R}(x, y) = \begin{cases} 1, & (x, y) \in S_1. \\ 0, & (x, y) \notin S_1. \end{cases} \quad (3)$$

2.2.2 Case 2: the incoming call requests for data rate $2R$

If the incoming call requests for data rate $2R$, the situation is more complicated than case 1. If the occupied codes for data rate R are too fragmented, the code blocking might occur and the call is rejected even when the system has enough capacity. In this case, it can be observed that the call blocking always happens in the following set of states,

$$S_2 = \{(x, y) \mid 2x + 2y \geq N, x + 2y \leq N\}. \quad (4)$$

Namely, at state (x, y) the code blocking might occur only if $x \geq (N - 2y)/2$. We call these states as *unsafe states*. Nevertheless, an unsafe state does not necessarily lead to a

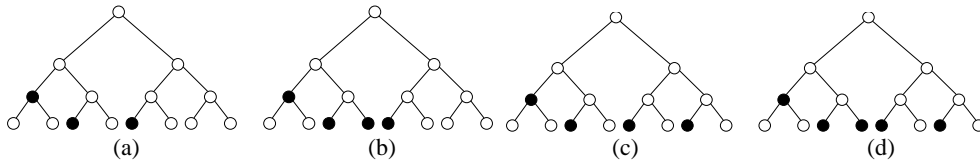


Fig. 2. The scenarios of safe and unsafe states.

code blocking. On the other hand, a *safe state* would never cause a code blocking. In Fig. 2, we illustrate some different scenarios of safe and unsafe states upon the arrival of a incoming call requesting for data rate $2R$. In Fig. 2 (a) $N = 8$, $x = 2$ and $y = 1$, it is a safe state, and a call blocking does not occur. In Fig. 2 (b) $N = 8$, $x = 3$ and $y = 1$, it is an unsafe state but no call blocking occurs. In Fig. 2 (c) $N = 8$, $x = 3$ and $y = 1$, it is also an unsafe state and a call blocking exists. In Fig. 2 (d) $N = 8$, $x = 4$ and $y = 1$, it shows another unsafe state case with a call blocking.

From above, it is observed that a call blocking always occurs in an unsafe state. The conditional blocking probability in an unsafe state depends on the distribution of occupied codes, that is, the distribution of the $x + y$ calls.

Given a state $(x, y) \in S_2$, the total number of combinations for allocating the $x + y$ calls is $C_y^{N/2} \cdot C_x^{N-2y}$. Upon the arrival of an incoming call with requested rate $2R$, a code blocking occurs if at least one of every pair of two sibling codes (*i.e.* two codes with the same parent in the code tree) of data rate R is occupied. To count the possible combinations in such space, the number of combinations for allocating the y calls is derived first. The value is $C_y^{N/2}$.

Next, consider the allocation of the x calls. Recall that a state (x, y) is an unsafe state, if $2x \geq N - 2y$. Therefore, we divide the x calls into two groups: $2x - (N - 2y)$ calls and $N - 2y - x$ calls. In a blocking situation, the first group of $2x - (N - 2y)$ calls fully occupies $[2x - (N - 2y)]/2$ pairs of sibling codes of data rate R . Note that there are totally $(N - 2y)/2$ pairs of sibling codes of data rate R available, after y calls are allocated. Therefore, the number of combinations for allocating the first group is equivalent to that for picking $[2x - (N - 2y)]/2$ pairs out of $(N - 2y)/2$ pairs, which is $C_{x-(N-2y)/2}^{(N-2y)/2}$. Moreover, the second group of $N - 2y - x$ calls could be assigned to any code of the unallocated pairs of sibling codes, thus the number of combinations is 2^{N-2y-x} . Finally, the total number of combinations that results in a call blocking is $C_y^{N/2} \cdot C_{x-(N-2y)/2}^{(N-2y)/2} \cdot 2^{N-2y-x}$. We assume each combination has the equal opportunity of occurrence. Thus, the conditional blocking probability of an unsafe state (x, y) upon the arrival of a data rate $2R$ is given by

$$P_{B|2R}(x, y) = \frac{C_y^{N/2} \cdot C_{x-(N-2y)/2}^{(N-2y)/2} \cdot 2^{N-2y-x}}{C_y^{N/2} \cdot C_x^{N-2y}} = \frac{C_{x-(N-2y)/2}^{(N-2y)/2} \cdot 2^{N-2y-x}}{C_x^{N-2y}}. \quad (5)$$

Define the blocking probability of a state (x, y) , whether safe state or unsafe state, upon the arrival of a data rate $2R$ to be $b(x, y)$, and short noted as b_y^x , then

$$b_y^x = b(x, y) = \begin{cases} \frac{C_{x-(N-2y)/2}^{(N-2y)/2} \cdot 2^{N-2y-x}}{C_x^{N-2y}}, & \text{if } x \geq \frac{N-2y}{2}, \\ 0, & \text{otherwise.} \end{cases} \quad (6)$$

Thus, the probability that a blocking does not occur in an unsafe state (x, y) is given by an available function, short noted as a_y^x

$$a_y^x = a(x, y) = 1 - b(x, y). \quad (7)$$

To find the steady-state probability $p(x, y)$, the flow balance equations are derived.

$$\begin{aligned} & [\delta(x+1, y) \cdot \lambda_1 + \delta(x, y+1) \cdot a_y^x \lambda_2 + \delta(x-1, y)x\mu_1 + \delta(x, y-1)y\mu_2] \cdot p(x, y) \\ &= \delta(x-1, y)\lambda_1 \cdot p(x-1, y) + \delta(x, y-1)a_{y-1}^x \lambda_2 \cdot p(x, y-1) + \delta(x+1, y)(x+1) \\ & \quad \cdot \mu_1 \cdot p(x+1, y) + \delta(x, y+1)(y+1) \cdot \mu_2 \cdot p(x, y+1), \forall (x, y) \in S \end{aligned} \quad (8)$$

where 0-1 function $\delta(x, y)$ is defined as $\delta(x, y) = \begin{cases} 1 & \text{if } (x, y) \in S \\ 0 & \text{otherwise} \end{cases}$, and we assume that $p(x, y) = 0$ and $a_y^x = 0$, if $(x, y) \notin S$. Since all probabilities sum to 1, we have

$$\sum_{(x,y) \in S} p(x, y) = \sum_{x=0}^N \sum_{y=0}^{\lfloor (N-x)/2 \rfloor} p(x, y) = 1. \quad (9)$$

Thus, the steady-state probabilities $p(x, y)$'s can be found by solving the above equations.

To obtain the blocking probability of the system $Q(N, \lambda_1, \mu_1, \lambda_2, \mu_2)$, two possible blocking cases are considered as follows. For case 1, $S_1 = \{(x, y) \mid x + 2y = N\}$, the states $(0, N/2)$, $(2, N/2 - 1)$, \dots , $(N - 2, 1)$ and $(N, 0)$ are located at the lower boundary of the Markov chain in Fig. 3. The blocking probability P_1 can be expressed as

$$P_1 = \sum_{(x,y) \in S_1} p(x, y) = \sum_{y=0}^{N/2} p(N - 2y, y). \quad (10)$$

For case 2, the call blocking probability P_2 can be obtained as

$$P_2 = \sum_{(x,y) \in S_2} p(x, y) \cdot b(x, y) = \sum_{y=0}^{N/2} \sum_{x=(N-2y)/2}^{N-2y} p(x, y) \cdot b(x, y). \quad (11)$$

3. OVFS CODE-BASED ALLOCATION SCHEME WITH QOS MANAGEMENT

In this section, we propose the OVFS code-based resource allocation schemes with QoS management for W-CDMA systems. The proposed schemes exactly reflect the reality of OVFS code tree in W-CDMA systems. In addition, we extend the basic model developed in section 2 to the proposed schemes.

3.1 Guard Code Schemes for Prioritized Traffic

As we have stated in former section, some guard channel schemes are proposed for

QoS consideration, in which resources are reserved for the prioritized calls. For the case of two service classes, the continuity of service in wireless communication is measured by new call blocking probability and handoff call dropping probability. However, handoff calls are more sensitive to interruptions and have higher priority than new calls. Thus, dropping a handoff call is more unacceptable than blocking a new call. Therefore, how to minimize the handoff dropping probability is an important issue in radio resource management of wireless networks systems.

Many call admission control schemes have been proposed to minimize handoff dropping probability. The static guard channel [3] is a straight and easy scheme to implement. This scheme reserves a portion of channels for handoff calls especially. At the beginning, the system allocates channels to both new calls and handoff calls. While the occupied capacity reaching a threshold, only handoff calls are accepted and new calls will be blocked.

In W-CDMA systems, because of the limited capacity and OVFS codes, the call blocking may occur while the capacity is fully occupied or the available OVFS codes are exhausted. Compared with channel-based allocation schemes, the rigid restrictions of OVFS code tree may lead to the extra *code blocking*, in which a call is blocked due to the fragmentation of free codes even though the system has enough capacity. The code blocking probability influences the overall system performance significantly in W-CDMA systems. Although the code blocking will be reduced by code reassignment strategies, however, it accompanies the signal overhead. For the consideration of signal overhead, we suppose that the code reassignment is not permitted in this paper.

In our work, we consider the guard channel scheme at code level rather than channel level. That is, we reserve some OVFS codes for handoff calls. We call this scheme as guard code scheme. In the guard code scheme, we reserve some OVFS codes for handoff calls. The remaining codes are shared by new calls and handoff calls. At the beginning, the system allocates the shared codes to either new calls or handoff calls. While the number of available codes is less than predefined threshold, that is, the shared codes are fully occupied, only handoff calls are accepted.

In this section, although we discuss the guard code schemes in the case of two service classes, the proposed schemes can be extended and applied to the cases of multiple service classes.

3.2 Analytical Models for Guard Code Schemes

In this section, we extend the basic model developed in section 2 to the proposed guard code schemes. Let N denote the total capacity of the OVFS code tree, λ_{1n} and λ_{2n} indicate the arrival rates for new calls from class R and class $2R$, the service time is assumed to be exponentially distributed with mean $1/\mu_{1s}$ and $1/\mu_{2s}$ respectively. At the same times, λ_{1h} and λ_{2h} denote the arrival rates for handoff calls from class R and class $2R$, the dwell time of calls in a cell follows exponential distributed with mean $1/\mu_{1d}$ and $1/\mu_{2d}$, respectively. Then, the calls holding time for class R and $2R$ is exponential distributed with mean $1/(\mu_{1s} + \mu_{1d})$ and $1/(\mu_{2s} + \mu_{2d})$, denoted as $1/\mu_1$ and $1/\mu_2$ respectively.

We reserve a number of OVFS codes (reserved capacity G , either request for code R or $2R$) for handoff calls. The remaining capacity is shared by new calls and handoff calls. At the beginning, the system allocates the shared codes to either new calls or handoff calls.

While the available capacity is less than G , only handoff calls are accepted. The flow balance equations in Eq. (8) are rewritten as:

$$\begin{aligned} & [\delta(x+1, y) \cdot \lambda_1(x, y) + \delta(x, y+1) \cdot a_y^x \lambda_2(x, y) + \delta(x-1, y)x\mu_1 + \delta(x, y-1)y\mu_2] \cdot p(x, y) \\ & = \delta(x-1, y)\lambda_1(x-1, y) \cdot p(x-1, y) + \delta(x, y-1)a_{y-1}^x \lambda_2(x, y-1) \cdot p(x, y-1) \\ & \quad + \delta(x+1, y)(x+1) \cdot \mu_1 \cdot p(x+1, y) + \delta(x, y+1)(y+1) \cdot \mu_2 \cdot p(x, y+1), \forall (x, y) \in S \end{aligned} \quad (12)$$

where 0-1 function $\delta(x, y)$ is defined as $\delta(x, y) = \begin{cases} 1 & \text{if } (x, y) \in S \\ 0 & \text{otherwise} \end{cases}$, and we assume that $p(x, y) = 0$ and $a_y^x = 0$, if $(x, y) \notin S$.

Arrival rate $\lambda_1(x, y)$ and $\lambda_2(x, y)$ are defined as:

$$\lambda_1(x, y) = \begin{cases} \lambda_{1n} + \lambda_{1h}, & \text{if } x+2y < N-G \\ \lambda_{1h}, & \text{if } x+2y \geq N-G \end{cases} \quad (13)$$

$$\lambda_2(x, y) = \begin{cases} \lambda_{2n} + \lambda_{2h}, & \text{if } x+2y < N-G \\ \lambda_{2h}, & \text{if } x+2y \geq N-G \end{cases} \quad (14)$$

The new call blocking and handoff dropping probability for class R are

$$P_{1n} = \sum_{x+2y \geq N-G} p(x, y), \quad (15)$$

$$P_{1h} = \sum_{x+2y=N} p(x, y). \quad (16)$$

The new call blocking and handoff dropping probability for class $2R$ are

$$P_{2n} = \sum_{x+2y \geq N-G} p(x, y) + \sum_{x+2y < N-G \wedge 2x+2y \geq N} p(x, y) \cdot b(x, y), \quad (17)$$

$$P_{2h} = \sum_{x+2y \geq N-1} p(x, y) + \sum_{x+2y < N-1 \wedge 2x+2y \geq N} p(x, y) \cdot b(x, y). \quad (18)$$

Where $b(x, y)$ is the blocking function defined in Eq. (6)

3.3 Guard Code Schemes for Multiple Service Classes

Our proposed guard code schemes and analytical models could be applied to the cases of more complicated multiple service classes. In this section, we extended our schemes and models to the case of three service classes. The case of more complex schemes for multiple priority classes could also be carried out by using the technique we proposed.

Consider the channel-based dual threshold bandwidth reservation (DTBR) scheme proposed in [6], which discusses three service classes: handoff voice calls, new voice calls and data calls. We consider the same service classes and priorities but extend to be OVFS code-based schemes for W-CDMA systems. Because the data calls can tolerate

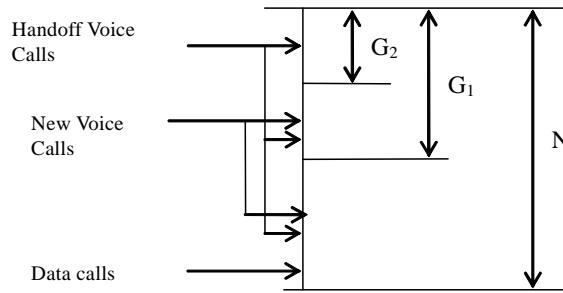


Fig. 3. Three classes priority control scheme.

certain degree of service degradation, the voice calls have higher priorities than the data calls. As we have mentioned previously, the handoff voice calls have higher priorities than new voice calls.

The total capacity N are divided into three regions by two guard thresholds G_1 and G_2 ($G_1 > G_2$) as in Fig. 3. We reserve guard codes G_1 for voice calls, and reserve guard codes G_2 for handoff voice calls exclusively. The pool codes $N - G_1$ are shared by all the calls. At the beginning, both data calls and voice calls are admitted. When the capacity of occupied codes exceeds $N - G_1$, then only voice calls are accepted. When the capacity of occupied codes exceeds $N - G_1$, then only handoff voice calls with highest priority can be accepted. The handoff voice call will be dropped only if there is no available code in the code tree.

Let λ_{1vh} , λ_{1vn} and λ_{1d} indicate the arrival rates for handoff voice calls, new voice calls and data calls from class R , and λ_{2vh} , λ_{2vn} and λ_{2d} are arrival rates from class $2R$ respectively. The calls holding time for class R and $2R$ is exponential distributed with mean $1/\mu_1$ and $1/\mu_2$ respectively.

As Eq. (12), the arrival rate functions $\lambda_1(x, y)$ and $\lambda_2(x, y)$ are defined as:

$$\lambda_1(x, y) = \begin{cases} \lambda_{1d} + \lambda_{1vn} + \lambda_{1vh}, & \text{if } x + 2y < N - G_1 \\ \lambda_{1vn} + \lambda_{1vh}, & \text{if } N - G_1 \leq x + 2y < N - G_2, \\ \lambda_{1vh}, & \text{if } x + 2y \geq N - G_2 \end{cases} \quad (19)$$

$$\lambda_2(x, y) = \begin{cases} \lambda_{2d} + \lambda_{2vn} + \lambda_{2vh}, & \text{if } x + 2y < N - G_1 \\ \lambda_{2vn} + \lambda_{2vh}, & \text{if } N - G_1 \leq x + 2y < N - G_2. \\ \lambda_{2vh}, & \text{if } x + 2y \geq N - G_2 \end{cases} \quad (20)$$

The blocking probability of data calls, new voice calls and handoff calls for class R are:

$$P_{1d} = \sum_{x+2y \geq N-G_1} p(x, y), \quad (21)$$

$$P_{1vn} = \sum_{x+2y \geq N-G_2} p(x, y), \quad (22)$$

$$P_{1vh} = \sum_{x+2y=N} p(x, y). \quad (23)$$

The blocking probability of data calls, new voice calls and handoff calls for class $2R$ are:

$$P_{2d} = \sum_{x+2y \geq N-G_1} p(x, y) + \sum_{(x+2y < N-G_1) \wedge (2x+2y \geq N)} p(x, y) \cdot b(x, y), \quad (24)$$

$$P_{2vn} = \sum_{x+2y \geq N-G_2} p(x, y) + \sum_{(x+2y < N-G_2) \wedge (2x+2y \geq N)} p(x, y) \cdot b(x, y), \quad (25)$$

$$P_{2vh} = \sum_{x+2y \geq N-1} p(x, y) + \sum_{(x+2y < N-1) \wedge (2x+2y \geq N)} p(x, y) \cdot b(x, y). \quad (26)$$

4. NUMERICAL RESULTS

In this section, we present the numerical results and compare the blocking probability of different priority class traffics and different size of guard codes.

For the computational consideration, we choose capacity of code tree $N = 64$. In the case of two classes scheme, we consider guard code size $G = 4, 6, 8, 10, 12$ for comparisons. We assume that the arrival calls for classes request rate $1R$ have the same arrival rate with the calls for classes request rate $2R$. We fix the new calls arrival rate with $\lambda_{1n} = \lambda_{2n} = 0.2$, the let the handoff calls arrival rates vary from 0.05 to 0.5. The calls departure rate $\mu_1 = \mu_2 = 0.03$ in the cell for both classes request rate $1R$ and $2R$.

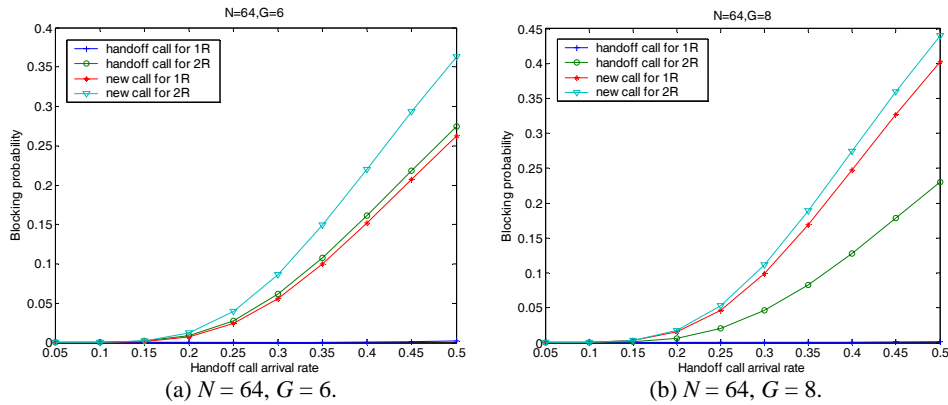


Fig. 4. The numerical results for different classes call arrivals.

In Fig. 4, we compare the blocking probability of new calls and handoff calls with request rate $1R$ and $2R$ respectively. In Fig. 4 (a), we set guard codes size G to be 6. The numerical results show that the class of new call arrivals with rate $2R$ has the highest blocking probability, and then handoff call arrival with rate $2R$. Because those two classes of calls need more capacity, the restrictions of OVFS code tree make it easy to cause code blocking and lead to call blocking. The handoff call arrivals and new call arrivals with rate $1R$ have better performance because of being less sensitive to the restriction of OVFS code tree. In Fig. 4 (b), we increase the guard codes size to be 8; the

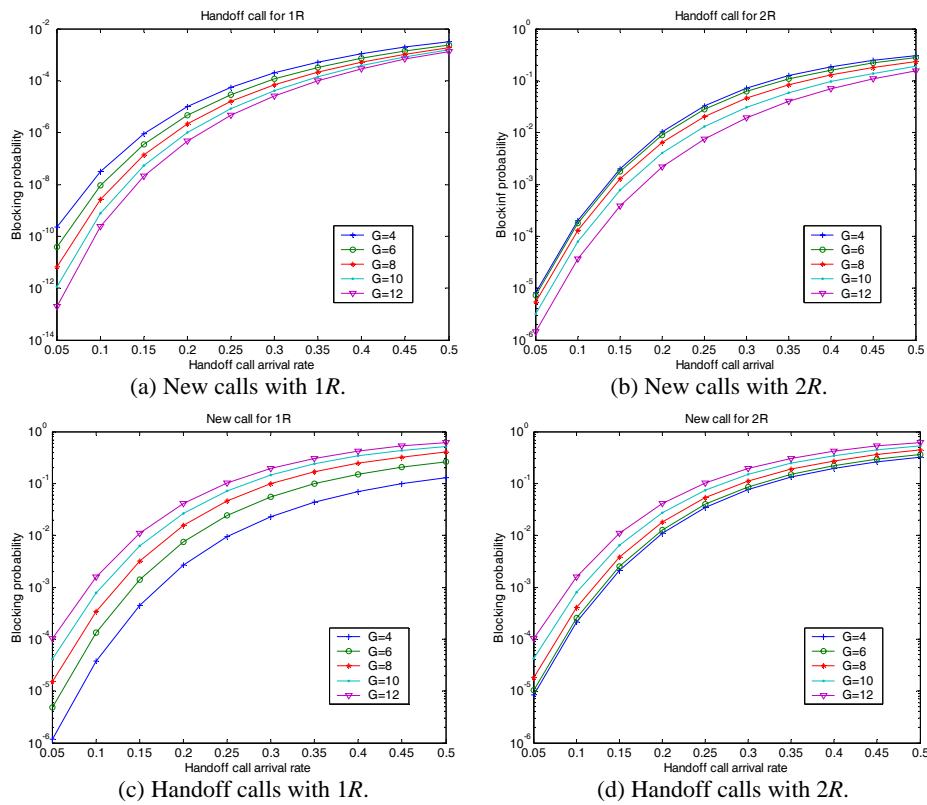


Fig. 5. The numerical results for different guard code sizes.

call blocking probability of the new calls arrival with rate $1R$ exceed the probability of handoff call arrival with rate $2R$. The function of guard codes becomes active obviously; the handoff calls are accepted with higher priority.

In Fig. 5, we illustrate the performance with different guard code size for different classes of traffic. In Figs. 5 (a) and (c), the bigger guard code size of the OVSF code, the lower blocking probability of the handoff arrival calls with rate $1R$, and so do the calls with $2R$ (in Figs. 5 (b) and (d)).

In Fig. 6, we illustrate the numerical results of three priority classes case presented in section 3.3. We also choose capacity of code tree $N = 64$, and compare four different cases of code size ($G_1 = 8, G_2 = 4$), ($G_1 = 12, G_2 = 4$), ($G_1 = 12, G_2 = 8$) and ($G_1 = 16, G_2 = 8$). We assume that the arrival calls for classes request rate $1R$ have the same arrival rate with calls for classes request rate $2R$. We fix the data calls arrival rate with $\lambda_{1d} = \lambda_{2d} = 0.2$, the let the voice calls arrival rates vary from 0.05 to 0.5. The new calls/handoff calls ratio of voice calls is 2:3. The calls departure rate $\mu_1 = \mu_2 = 0.03$ in the cell for both classes request rate $1R$ and $2R$. In Figs. 6 (a) and (b), the performance of data calls gets worse while the guard code G_1 increasing. However, the data calls can tolerant some degree of degradation, which is why we reserve guard codes for voice calls only. At the same times the performance of handoff voice calls get better because of the affections of

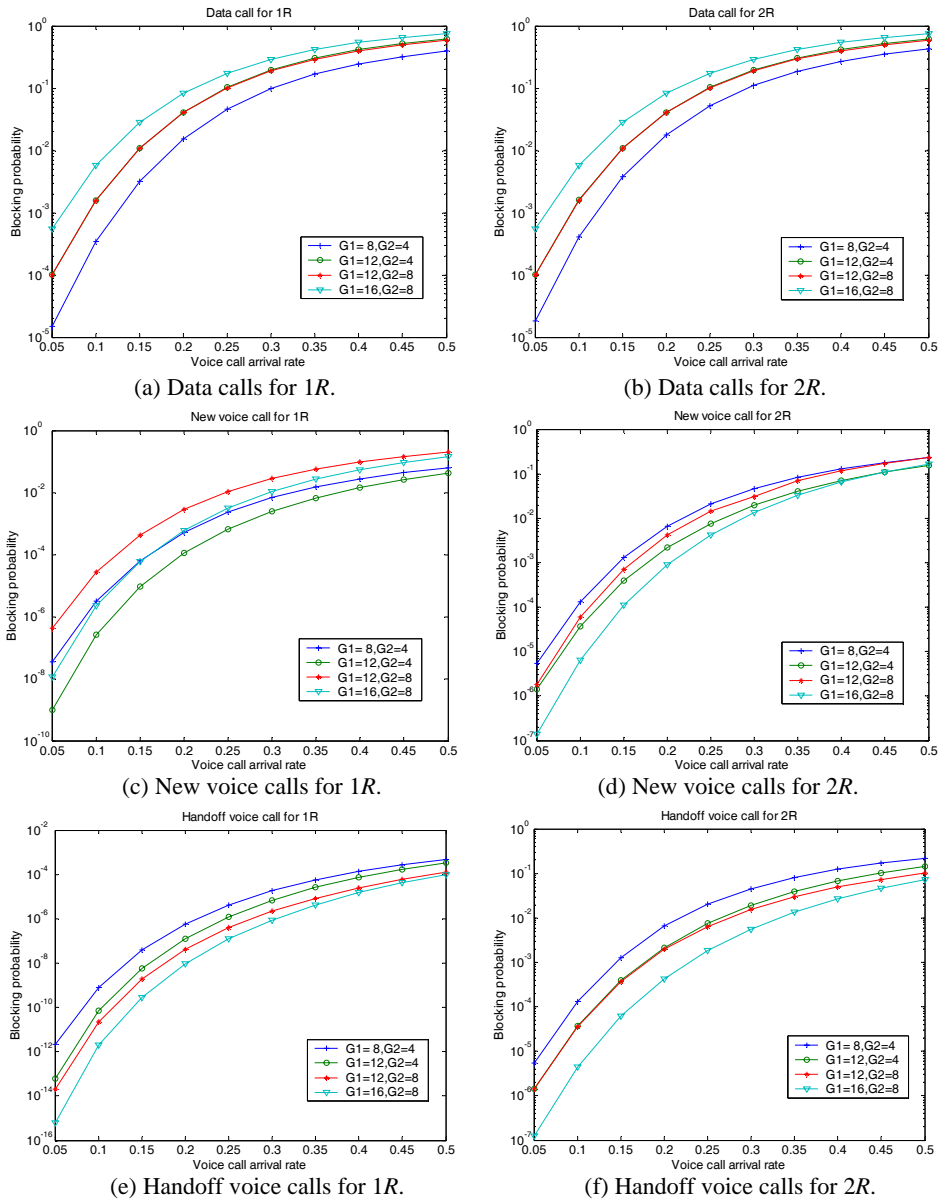


Fig. 6. The numerical results for different guard code sizes.

guard codes (see Figs. 6 (e) and (f)). In Figs. 6 (c) and (d), the performance of new voice calls varies depends on G_1 and G_2 , especially in G_2 .

The classes of request rate 1R and 2R have different results for different guard codes size. The restrictions of OVFS code tree would be an important factor for these results. For the purpose of QoS management, we reserve guard codes for high priority class calls. The blocking probabilities of low priority class call arrivals are increasing as the guard code size are bigger. Nevertheless, to block too many lower priority class call

arrivals may influence the total performance in the system. Thus, the size of guard channel plays an important role in guard channel schemes. The size of guard channels should be adjusted for different requirements of QoS guarantee. At the same times, the better total system performance should be maintained. How to determine the size of guard channel becomes a significant issue in designing guard channel schemes. There are many call admission control schemes are proposed to decrease the blocking probability of the low priority class calls under a predefined higher priority class blocking probability threshold to prompt the total system performance, and the size of guard channel are discussed also. Discussing these schemes is not the scope of this paper, however, our proposed model provides an easy and extensible tool to analyze and evaluate the system performance of the OVSF code based call admission control schemes.

5. CONCLUSION

In next generation wireless communication systems, multimedia applications and services are supported and growing rapidly. The multi-class services have different QoS requirements in terms of data rate, delay tolerance, *etc.* The role of QoS management becomes more important in future wireless communication systems. Many researches are conducted to propose efficient resource allocation schemes with QoS management to improve the system performance. In this paper, we have developed an OVSF code based analytical model to evaluate performance of resource allocation schemes with QoS management in W-CDMA Systems.

In contrast to channel based model, our proposed model is an OVSF code based model that exactly reflects the characteristics and restrictions of an OVSF code tree, and is more suitable to W-CDMA systems than channel based analytical models. The proposed model is easy to construct and analyze system performance of call admission control schemes with QoS management in W-CDMA systems. It also can be extended to more complicated multi-classes traffic systems.

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