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Quantized-Non Quantized Code Tree Partitioning and Reduction in Internal-External Fragmentation

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Abstract The use of orthogonal variable spreading factor codes as channelization codes in downlink give rise to code blocking probability due to orthogonal nature of codes. This will further lead to increase in call establishment delay to locate a suitable code which can be assigned to new call request. Code blocking is mainly due to fragmentation of lower rate calls in code tree, which blocks capacity of higher rate codes and consequently blocking of higher rate call requests. In this paper, an assignment approach is proposed which addresses fragmentation due to scattered codes *i.e. external fragmentation* and *internal fragmentation* associated with non-quantized rates too. The code tree is virtually divided in two portions, one for quantized and another for non quantized rates. This will lead to reduction in number of code searches before assignment of call to a code. In addition, data calls are queued in buffer to handle voice calls. The data calls share the capacity of a assigned code, to reduce code blocking of real time calls. The data calls are handled using a code of higher capacity for most of the time which reduces their call duration. The proposed scheme is compared with existing novel schemes to show its ascendancy over them.

Keywords OVSF · Code blocking · Code searches · Single code assignment · Call establishment delay

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1 Introduction

In delay sensitive applications like video in multimedia systems, voice transmission, assignment of calls to a minimum rate is required to meet quality of service (QoS) while delay insensitive calls (such as data) being handled(transmitted) at any rate is possible beyond or below minimum rate requested. The traffic arrival in 3G and beyond network is dominated by such type of calls. Wide band code division multiple access (WCDMA) [1] uses OVSF codes to handle calls arrive in networks. The spreading factor (*SF*) of OVSF codes differ according to the application. The higher is the rate requirement of user, lower is the SF. However, their product is always 3.84$Mcps$. For a OVSF system handling users of L distinct classes, the $SF_{max} = 2^{L-1}$.

A binary tree is used to generate OVSF code line structure [2]. The code in OVSF tree is represented by $C_{l,n_l} = 2^{L-1}$, where l represents its layer number varying from 1 to L (L is height of code tree) and n_l, denotes the position of a code in layer l, $1 \leq n_l \leq 2^{L-l}$. The code in highest layer is the root code and the code in lowest layers are leaf codes. The rate of a code is quantized $i.e.$ $2^{l-1}R$ $(1 \leq l \leq L)$, where R is the capacity of leaf codes = 7.5 $Kbps$ for WCDMA networks. The total capacity of code tree and total capacity of all codes of any layer in $2^{L-1}R$. The capacity is enough to handle many calls and should provide best option for mobile networks, due to the orthogonal nature of codes, an assigned code block all its parent and children codes for assignment, only siblings are left scattered in code tree. This problem needs careful assignment of a call to maximize throughput or to reduce code blocking probability of users.

1.1 Problem Statement

How codes are blocked for assignment which leads to blocking of a new call request even though system has enough to support the call as explained using status of code tree in Fig. 1. The total capacity of code tree is $32R$. The used capacity is $10R$ $[2R(R+R)]$ due to $C_{1,7}$ and $C_{1,8}$, $4R(2R+2R)$ due to $C_{2,5}$ and $C_{2,15}$ and $4R$ due to $C_{3,4}$). The total vacant capacity = $(32-10)R = 22R$. A new call request of rate $16R$ is blocked, though system has $22R$ vacant capacity. This is due to scattered vacant capacity in code tree. This is blocking due to external fragmentation. The other reason of code blocking is internal fragmentation. This is due the quantized rate handling capability of OVSF code tree. If a new user with rate kR, $k \neq 2^n$ arrives, the user require a code with capacity $2^m R$, where $k < 2^m$ for minimum m. This will lead to a wastage capacity $= (2^m - k)R$ and blocking of new calls even though capacity is vacant.

1.2 Related Work

The code assignment schemes which do not incorporate code sharing can be categorized into single code and multi code assignment schemes. The single code assignment scheme used single code to handle incoming calls [3]. The leftmost code assignment (LCA) [4], crowded first assignment (CFA) [4], fixed set partitioning (FSP) [5] and dynamic code assignment (DCA) [6] are single code assignment schemes. In the leftmost code assignment scheme, the code assignment is done from the left side of the code tree. In crowded first assignment, the code is assigned to a new call such that the availability of vacant higher rate codes in future is more. In the fixed set partitioning, the code tree is divided into a number of sub trees according to the input traffic distribution. In dynamic code assignment scheme, the blocking probability is reduced using reassignments based on the cost function. The DCA scheme requires extra information to be transmitted to inform the receiver about code reassignments. The incoming calls are converted into quantized rates. A fast OVSF code assignment design is given in [7] which aims to reduce number of codes searched with optimal/suboptimal code blocking. The code assignment scheme uses those vacant codes whose parents are already blocked. This leads to occurrence of more vacant codes in groups, which ultimately leads to less code blocking for higher rate calls. The integration of calls is done in [8] for allocation of OVSF codes when a quantized or non quantized call arrives, and further, the voice calls and data calls are treated differently as former are delay sensitive and later can be stored in buffer. The single code assignment schemes are simpler, cost effective and require single rake combiner at the BS/UE. The multi code assignment schemes use multiple codes in the OVSF code tree and hence multiple rake combiners to handle single call. It reduces code blocking compared to single code assignment schemes but the cost and complexity is more [9–11]. The multi-code assignment schemes provide additional benefit of handling non quantized (not in the form of $2^{l-1}R,\ l \in [1,\ L]$ data rates. The DCA scheme with different QoS requirements is given in [12]. The performance of fixed and dynamic code assignment schemes with blocking probability constraint is given in [13]. The throughput performance is proved to be better in this paper. The multi rate multi code compact assignment (MMCA) [14] scheme uses the concept of compact index to accommodate QoS differentiated mobile terminals. The maximally flexible assignment scheme [15] discusses two code assignments namely rearrangeable code assignment and non rearrangeable code assignment schemes. It define flexibility index to measure the capability of assignable code set. Both schemes provide the maximal flexibility for the code tree after each code assignments. The code/slot sharing in all above schemes further reduces the code blocking. The code assignment scheme in [16] uses the higher layer code sharing on the periodic basis. This is significant requirement for calls with large peak to average ratio of data rates. The code utilization is increased due to code sharing. Using idle/unused code slots for bursty traffic, the fairness and per connection data rate guarantee is achieved. The code assignment scheme discussed in [17] describes three scheduling algorithms to support multimedia transmissions. The credit management and compensation mechanism provides rate guarantee and fair access to mobile terminals. Each call is allowed to use multiple codes in time sharing manner. The channel sensitive algorithm is given to use multiple codes when there are channel errors leading to bad signals. For bad quality transmission, codes with higher spreading factors are used. It defines shared count of ancestors to use the code from partially shared area or fully shared area. The topdown scheme [18] starts code search from top of the code tree to achieve optimum code blocking with reduced call establishment delay. The single code design in [19] is for quantized rates and divides the OVSF code tree capacity according to the arrival distribution. The change in the distribution is dynamically reflected in the division of the code tree capacity for different rates. The multicode design is preferred for the system dominated by non quantized rates. In this paper, a code assignment scheme is proposed which differentiates type of calls before assignment.

The rest of the paper is organized as follows. Section 2 explains the proposed scheme. Results and simulations are done in Sect. 3. Finally, paper is concluded in Sect. 4.

2 Proposed Scheme

Consider an OVSF based WCDMA network using a code tree of L layer ($L = 8$). A code in layer l is defined as C_{l,n_l}, $1 \le n_l \le 2^{L-l}$, $1 \le l \le L$. All the codes in code tree have quantized rates of the form $2^{l-1}R$, where $1 \le l \le L$. If a code is assigned to quantized call

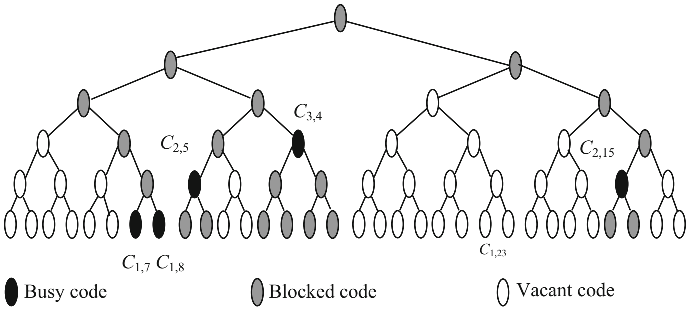

Fig. 1 OVSF Code tree with six layers

of rate $kR\{= 2^j,\ j \in [0, 4]\}$, then total capacity of code is utilized and as kR $\{k = 2^{l-1}\}$ code of layer $l^k | l^k = (log_2 k + 1) = I : integer$ is assigned to it. However, for non quantized call request of rate $kR(l^k = log_2 k + 1) \neq I$ and call will be assigned to a code of rate $(2^{l^k - 1})R$ which will lead to wastage of $(2^{l^k - 1} - k)$ R capacity and will result in blocking of new call, even though enough capacity is available to handle the call. The proposed scheme before assignment of call to a code differentiate it on the basis of call type and request rate type

1. Call type
   a) Voice
   b) Data
2. Request rate type
   a) Quantized
   b) Non quantized

The code tree is virtually divided equally between quantized and non quantized calls. The assignment scheme will search codes from C_{l,n_l}, $1 \leq n_l \leq 2^{L-l-1}$ for quantized calls and from $(2^{L-l-1} + 1) \leq n_l \leq (2^{L-l})$. Define γ^{U}_{l,n_l}, γ^{Un}_{l,n_l} asused, unused capacity of code C_{l,n_l}, γ^{B}_{max} is maximum capacity which can be queued in buffer, γ^{B} is capacity of calls waiting in buffer at any instant. The call can be handled by code tree if $\gamma^{Un}_{L,n_L} + 2^{l-1}R \leq 2^{L-1}R$.

The algorithm works as follows:

1) Voice calls-quantized
   Search all vacant codes from $1 \leq n_l \leq 2^{L-l-1}$. For all vacant codes, find immediate parent code with $\min(\gamma^{Un}_{l',n_{l'}})$. For a tie check status of codes in layers from $((l + 1) \leq l' \leq L)$ and if tie occurs for codes $C_{l^1,n_{l1}}$ & $C_{l^2,n_{l2}}$, than assign call to a code whose parent(s) have $min(\gamma^{Un}_{l',n_{l'}}) \forall C_{l,n_l} | C_{l'^1,n_{l'1}} \neq C_{l'^2,n_{l'2}}$ and whose parent in all layers are different.
   a) If
      Vacant code exists, assign call to it and update $\gamma^{U}_{l',n_{l'}} = \gamma^{U}_{l',n_{l'}} + 2^{l-1}R$ and $\gamma^{Un}_{l',n_{l'}} = \gamma^{Un}_{l',n_{l'}} - 2^{l-1}R$.
   b) Else if $(\gamma^{B} \leq \gamma^{max})$
      List all codes handling data calls in layer l', $C_{l',n_{l'}}$, $l' > l$,
      i) Start from $l' = l + 1$, $\forall C_{l',n_{l'}}$

ii) Find $\gamma^{Un}_{l',n_{l'}} + \min\left[2^{l_m-1}R\right] \geq 2^{l-1}R, 1 \leq l_m \leq (l+1)$, where rate $2^{l_m-1}R$ is the rate of mth ongoing call that can be placed in queue to handle voice call request.

iii) If
A code satisfying above condition exists, assign call to code $C_{l',n_{l'}}$ and queue call of rate $2^{l_m-1}R$ in buffer. The used capacity, unused capacity and buffer capacity are updated as $\gamma^{Un}_{l',n_{l'}} = \gamma^{Un}_{l',n_{l'}} + 2^{l_m-1}R - 2^{l-1}R$, $\gamma^{U}_{l',n_{l'}} = \gamma^{U}_{l',n_{l'}} - 2^{l_m-1}R + 2^{l-1}R$ and $\gamma^B = \gamma^B + 2^{l_m-1}R$ respectively.

iv) Else if $l' = l' + 1$.

v) Repeat steps (*ii–iii*).

vi) End
No vacant code of rate $2^{l-1}R$ is available in left portion of code tree.

c) Else if
Search vacant codes from $(2^{L-l-1}+1) \leq n_l \leq (2^{L-l})$ in layer l using LCA.

i) If

ii) A vacant code is available, call will be assign to it and update $\gamma^{U}_{l',n_{l'}} = \gamma^{U}_{l',n_{l'}} + 2^{l-1}R$ and $\gamma^{Un}_{l',n_{l'}} = \gamma^{Un}_{l',n_{l'}} - 2^{l-1}R$.
Else if
Search code with $[\max(\gamma^{U}_{l',n_{l'}})\&\&\gamma^{Un}_{l',n_{l'}} \geq 2^{l-1}R)]$ to keep code utilization maximum.

iii) Else repeat step (b) in right portion of the code tree.

iv) End

d) Else
Block the call.

e) End.

2) Non quantized voice call
Search a vacant code from $2^{L-l-1} \leq n_l \leq 2^{L-l}$ using LCA, such that $k \geq 2^{l^k}$ and parent code(s) with $min(\gamma^{Un}_{l',n_{l'}})$, where $(l+1) \leq l' \leq L$.

a) If
A vacant code exist assign call to it and update $\gamma^{U}_{l',n_{l'}} = \gamma^{U}_{l',n_{l'}} + kR$ and $\gamma^{Un}_{l',n_{l'}} = \gamma^{Un_{l'}}_{l',n} - kR$.

b) Else if $(\gamma^B \leq \gamma^{max})$
Find $(l^k = log_2 k + 1)$ and l^k. List all codes handling data calls in layer l', $C_{l',n_{l'}}$, $l' > l^k$.

i) Start from $l' = l+1$, $\forall C_{l',n_{l'}}$

ii) Find $\gamma^{Un}_{l',n_{l'}} + min\left[2^{l_m-1}R\right] = 2^{l-1}R, 1 \leq l_m \leq (l+1)$, $2^{l_m-1}R$ is the rate of mth ongoing data call that can be placed in queue to handle new voice call request.

iii) If
A code satisfying above condition exists, assign call to code $C_{l',n_{l'}}$ and queue call of rate $2^{l_m-1}R$ in buffer. The used capacity, unused capacity and buffer capacity are updated as $\gamma^{Un}_{l',n_{l'}} = \gamma^{Un}_{l',n_{l'}} + 2^{l_m-1}R - 2^{l-1}R$, $\gamma^{U}_{l',n_{l'}} = \gamma^{U}_{l',n_{l'}} - 2^{l_m-1}R + 2^{l-1}R$ and $\gamma^B = \gamma^B + 2^{l_m-1}R$ respectively.
If $(\gamma^{Un}_{l',n_{l'}} \neq 0)$
Find the call in buffer of rate $2^{l_B-1}R$ or kR with maximum capacity which can

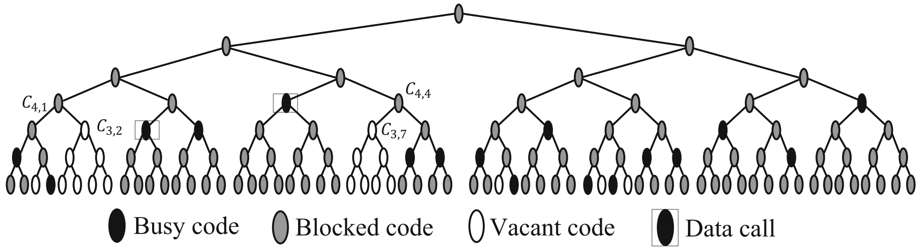

Fig. 2 Example for single code assignment scheme

utilize unused capacity of code $C_{l',n_{l'}}$ $i.e\gamma^{Un}_{l',n_{l'}}$ and update $\gamma^B = \gamma^B + 2^{l_B-1}R$.
End.
 iv) Else $l' = l' + 1$.
 v) Repeat steps (*ii–iii*).
 v) End
c) Else if
Search a code from $1 \leq n_l \leq 2^{L-l-1}$handling non quantized voice call $k_i R,\ k_i \neq 2^n$.
For a tie assign call to a code with $\min(\gamma^{Un}_{l',n_{l'}})$.
d) Else
Block the call.
e) End

The code assignment for the voice calls can be illustrated with code tree Fig. 2. For a new call of rate $4R$ which is quantized there are only two candidates which can be used to handle new call $C_{3,2}$ and $C_{3,7}$ with their first parents $C_{4,1}$ and $C_{4,4}$. The capacity utilized under $C_{4,1}$ and $C_{4,4}$ is $3R$ and $4R$ respectively. The new call will be assigned to the code $C_{3,7}$. If two new call request of rate $4R$ arrive simultaneously after assigning $C_{3,7}$. Then one of the call will be handled by assigning code $C_{3,2}$. The second call can be handled by interrupting ongoing data calls of same or higher rate and queue them in buffer. The codes handling data calls are $C_{3,3}$ and $C_{4,3}$ of rate $4R$ and $8R$ respectively. If $\gamma^{\mathrm{B}} + 4R \leq \gamma^B_{max}$, the voice call is assigned to $C_{3,3}$ and data call is placed in buffer. The updated buffer capacity is $\gamma^{\mathrm{B}} = \gamma^{\mathrm{B}} + 4R$.

2.1 Arrival of Data Calls

2.1.1 Quantized/ Non Quantized Data Calls

A new call of rate *kR* arrives

a) If ($\gamma^B = 0$)
Start search of vacant code for rate $kR = 2^{l'-1}R$, where, ($l' = l\ or\ l^k$) from higher layers.
 i) If
 A vacant code is available assign call to it.
 ii) Else
 Initialize $l' = L - 1$.
 While ($l' = 1$)
 Search a busy code $C_{l',n_{l'}}$ with max ($\gamma^{Un}_{l',n_{l'}}$).
 $l' = l' - 1$.

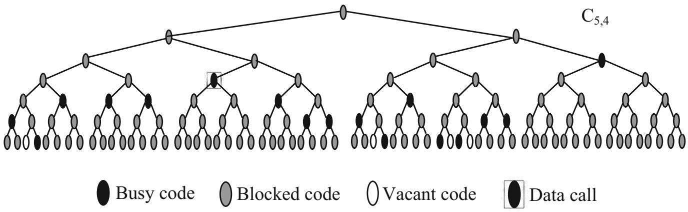

Fig. 3 Example for call departure process and arrival with calls in buffer

End.
Assign new call to code $C_{l',n_{l'}}$.

iii) Else if
Place call in buffer and update $\gamma^B = kR$.

iv) End

b) Else if $(\gamma^B \leq \gamma^{max})$
Place call in buffer and update $\gamma^B = \gamma^B + kR$.
c) Else
Block the call.
d) End.

2.1.2 Call in Buffer:

Calls in buffer are arranged in two ways.

1) Elapsed time in buffer
2) Capacity required to handle

or a combination of both.

If capacity of call to be handled which is selected using (1,2) in buffer is equal to capacity of call ended, then assign vacant code to this call.

2.2 Departure of a Call (Data/Voice)

When a call of rate $2^{l'-1}R$ ends, the vacant code of this call is used to handle the calls in buffer.

If
$\gamma^B \leq 2^{l'-1}R$, assign total buffer capacity to vacant code.
Else
Assign first call in buffer to vacant capacity. This will lead to transfer of data at a higher/ lower rate consequently call duration will decrease/ increase. Let t_d^{max} be maximum duration of call when assigned to a code of rate equal to rate requested.

$$t_{end} = t_d^{max} \frac{2^{l-1}}{2^{l'-1}} = t_d^{max} \times 2^{l-l'} \quad (1)$$

End

For $l \leq l'$, call is handled using a code of higher capacity $t_{end} \leq t_d^{max}$ and for $l \geq l'$ call is handled using a code of lower capacity $t_{end} \geq t_d^{max}$.

Table 1 Remaining time for completion of data calls of rate $2^{l-1}R$ after time t'

Assigned	Requested R	2R	3R	4R	5R	6R	7R	8R
R	$\frac{D}{R}$-t′	$\frac{D}{R}$-2t′	$\frac{D}{R}$-3t′	$\frac{D}{R}$-4t′	$\frac{D}{R}$-5t′	$\frac{D}{R}$-6t′	$\frac{D}{R}$-7t′	$\frac{D}{R}$-8t′
2R	$\frac{D}{2R}-\frac{t'}{2}$	$\frac{D}{2R}$-t′	$\frac{D}{2R}-\frac{3t'}{2}$	$\frac{D}{2R}$-2t′	$\frac{D}{2R}-\frac{5t'}{2}$	$\frac{D}{2R}$-3t′	$\frac{D}{2R}-\frac{7t'}{2}$	$\frac{D}{2R}$-4t′
3R	$\frac{D}{3R}-\frac{t'}{3}$	$\frac{D}{3R}-\frac{2t'}{3}$	$\frac{D}{3R}$-t′	$\frac{D}{3R}-\frac{4t'}{3}$	$\frac{D}{3R}-\frac{5t'}{3}$	$\frac{D}{3R}$-2t′	$\frac{D}{3R}-\frac{7t'}{3}$	$\frac{D}{3R}-\frac{8t'}{3}$
4R	$\frac{D}{4R}-\frac{t'}{4}$	$\frac{D}{4R}-\frac{t'}{2}$	$\frac{D}{4R}-\frac{3t'}{4}$	$\frac{D}{4R}$-t′	$\frac{D}{4R}-\frac{5t'}{4}$	$\frac{D}{4R}-\frac{3t'}{2}$	$\frac{D}{4R}-\frac{7t'}{4}$	$\frac{D}{4R}$-2t′
5R	$\frac{D}{5R}-\frac{t'}{5}$	$\frac{D}{5R}-\frac{2t'}{5}$	$\frac{D}{5R}-\frac{3t'}{5}$	$\frac{D}{5R}-\frac{4t'}{5}$	$\frac{D}{5R}$-t′	$\frac{D}{5R}-\frac{6t'}{5}$	$\frac{D}{5R}-\frac{7t'}{5}$	$\frac{D}{5R}-\frac{8t'}{5}$
6R	$\frac{D}{6R}-\frac{t'}{6}$	$\frac{D}{6R}-\frac{t'}{3}$	$\frac{D}{6R}-\frac{t'}{2}$	$\frac{D}{6R}-\frac{2t'}{3}$	$\frac{D}{6R}-\frac{5t'}{6}$	$\frac{D}{6R}$-t′	$\frac{D}{6R}-\frac{7t'}{6}$	$\frac{D}{6R}-\frac{4t'}{3}$
7R	$\frac{D}{7R}-\frac{t'}{7}$	$\frac{D}{7R}-\frac{2t'}{7}$	$\frac{D}{7R}-\frac{3t'}{7}$	$\frac{D}{7R}-\frac{4t'}{7}$	$\frac{D}{7R}-\frac{5t'}{7}$	$\frac{D}{7R}-\frac{6t'}{7}$	$\frac{D}{7R}$-t′	$\frac{D}{7R}-\frac{8t'}{7}$
8R	$\frac{D}{8R}-\frac{t'}{8}$	$\frac{D}{8R}-\frac{t'}{4}$	$\frac{D}{8R}-\frac{3t'}{8}$	$\frac{D}{8R}-\frac{t'}{2}$	$\frac{D}{8R}-\frac{5t'}{8}$	$\frac{D}{8R}-\frac{3t'}{4}$	$\frac{D}{8R}-\frac{7t'}{8}$	$\frac{D}{8R}$-t′
9R	$\frac{D}{9R}-\frac{t'}{9}$	$\frac{D}{9R}-\frac{2t'}{9}$	$\frac{D}{9R}-\frac{t'}{3}$	$\frac{D}{9R}-\frac{4t'}{9}$	$\frac{D}{9R}-\frac{5t'}{9}$	$\frac{D}{9R}-\frac{2t'}{3}$	$\frac{D}{9R}-\frac{7t'}{9}$	$\frac{D}{9R}-\frac{8t'}{9}$
10R	$\frac{D}{10R}-\frac{t'}{10}$	$\frac{D}{10R}-\frac{t'}{5}$	$\frac{D}{10R}-\frac{3t'}{10}$	$\frac{D}{10R}-\frac{2t'}{5}$	$\frac{D}{10R}-\frac{t'}{2}$	$\frac{D}{10R}-\frac{3t'}{5}$	$\frac{D}{10R}-\frac{7t'}{10}$	$\frac{D}{10R}-\frac{4t'}{5}$
11R	$\frac{D}{11R}-\frac{t'}{11}$	$\frac{D}{11R}-\frac{2t'}{11}$	$\frac{D}{11R}-\frac{3t'}{11}$	$\frac{D}{11R}-\frac{4t'}{11}$	$\frac{D}{11R}-\frac{5t'}{11}$	$\frac{D}{11R}-\frac{6t'}{11}$	$\frac{D}{11R}-\frac{7t'}{11}$	$\frac{D}{11R}-\frac{8t'}{11}$
12R	$\frac{D}{12R}-\frac{t'}{12}$	$\frac{D}{12R}-\frac{t'}{6}$	$\frac{D}{12R}-\frac{t'}{4}$	$\frac{D}{12R}-\frac{t'}{3}$	$\frac{D}{12R}-\frac{5t'}{12}$	$\frac{D}{12R}-\frac{t'}{2}$	$\frac{D}{12R}-\frac{7t'}{12}$	$\frac{D}{12R}-\frac{2t'}{3}$
13R	$\frac{D}{13R}-\frac{t'}{13}$	$\frac{D}{13R}-\frac{2t'}{13}$	$\frac{D}{13R}-\frac{3t'}{13}$	$\frac{D}{13R}-\frac{4t'}{13}$	$\frac{D}{13R}-\frac{5t'}{13}$	$\frac{D}{13R}-\frac{6t'}{13}$	$\frac{D}{13R}-\frac{7t'}{13}$	$\frac{D}{13R}-\frac{8t'}{13}$
14R	$\frac{D}{14R}-\frac{t'}{14}$	$\frac{D}{14R}-\frac{t'}{7}$	$\frac{D}{14R}-\frac{3t'}{14}$	$\frac{D}{14R}-\frac{2t'}{7}$	$\frac{D}{14R}-\frac{5t'}{14}$	$\frac{D}{14R}-\frac{3t'}{7}$	$\frac{D}{14R}-\frac{t'}{2}$	$\frac{D}{14R}-\frac{4t'}{7}$
15R	$\frac{D}{15R}-\frac{t'}{15}$	$\frac{D}{15R}-\frac{3t'}{15}$	$\frac{D}{15R}-\frac{t'}{5}$	$\frac{D}{15R}-\frac{4t'}{15}$	$\frac{D}{15R}-\frac{t'}{3}$	$\frac{D}{15R}-\frac{3t'}{5}$	$\frac{D}{15R}-\frac{7t'}{15}$	$\frac{D}{15R}-\frac{8t'}{15}$
16R	$\frac{D}{16R}-\frac{t'}{16}$	$\frac{D}{16R}-\frac{t'}{8}$	$\frac{D}{16R}-\frac{3t'}{16}$	$\frac{D}{16R}-\frac{t'}{4}$	$\frac{D}{16R}-\frac{5t'}{16}$	$\frac{D}{16R}-\frac{3t'}{8}$	$\frac{D}{16R}-\frac{7t'}{16}$	$\frac{D}{16R}-\frac{1t'}{2}$

Table 1 continued

Assigned	Requested 9R	10R	11R	12R	13R	14R	15R	16R
R	$\frac{D}{R}$-9t′	$\frac{D}{R}$-10t′	$\frac{D}{R}$-11t′	$\frac{D}{R}$-12t′	$\frac{D}{R}$-13t′	$\frac{D}{R}$-14t′	$\frac{D}{R}$-15t′	$\frac{D}{R}$-16t′
2R	$\frac{D}{2R}-\frac{9t'}{2}$	$\frac{D}{2R}$-5t′	$\frac{D}{2R}-\frac{11t'}{2}$	$\frac{D}{2R}$-6t′	$\frac{D}{2R}-\frac{13t'}{2}$	$\frac{D}{2R}$-7t′	$\frac{D}{2R}-\frac{15t'}{2}$	$\frac{D}{2R}$-8t′
3R	$\frac{D}{3R}$-3t′	$\frac{D}{3R}-\frac{10t'}{3}$	$\frac{D}{3R}-\frac{11t'}{3}$	$\frac{D}{3R}$-4t′	$\frac{D}{3R}-\frac{13t'}{3}$	$\frac{D}{3R}-\frac{14t'}{3}$	$\frac{D}{3R}$-5t′	$\frac{D}{3R}-\frac{16t'}{3}$
4R	$\frac{D}{4R}-\frac{9t'}{4}$	$\frac{D}{4R}-\frac{5t'}{2}$	$\frac{D}{4R}-\frac{11t'}{4}$	$\frac{D}{4R}$-3t′	$\frac{D}{4R}-\frac{13t'}{4}$	$\frac{D}{4R}-\frac{7t'}{2}$	$\frac{D}{4R}-\frac{15t'}{4}$	$\frac{D}{4R}$-4t′
5R	$\frac{D}{5R}-\frac{9t'}{5}$	$\frac{D}{5R}$-2t′	$\frac{D}{5R}-\frac{11t'}{5}$	$\frac{D}{5R}-\frac{12t'}{5}$	$\frac{D}{5R}-\frac{13t'}{5}$	$\frac{D}{5R}-\frac{14t'}{5}$	$\frac{D}{5R}$-3t′	$\frac{D}{5R}-\frac{16t'}{5}$
6R	$\frac{D}{6R}-\frac{3t'}{2}$	$\frac{D}{6R}-\frac{5t'}{3}$	$\frac{D}{6R}-\frac{11t'}{6}$	$\frac{D}{6R}$-2t′	$\frac{D}{6R}-\frac{13t'}{6}$	$\frac{D}{6R}-\frac{7t'}{3}$	$\frac{D}{6R}-\frac{5t'}{2}$	$\frac{D}{6R}-\frac{8t'}{3}$
7R	$\frac{D}{7R}-\frac{9t'}{7}$	$\frac{D}{7R}-\frac{10t'}{7}$	$\frac{D}{7R}-\frac{11t'}{7}$	$\frac{D}{7R}-\frac{12t'}{7}$	$\frac{D}{7R}-\frac{13t'}{7}$	$\frac{D}{7R}$-2t′	$\frac{D}{7R}-\frac{15t'}{7}$	$\frac{D}{7R}-\frac{16t'}{7}$
8R	$\frac{D}{8R}-\frac{9t'}{8}$	$\frac{D}{8R}-\frac{5t'}{4}$	$\frac{D}{8R}-\frac{11t'}{8}$	$\frac{D}{8R}-\frac{3t'}{2}$	$\frac{D}{9R}-\frac{13t'}{9}$	$\frac{D}{9R}-\frac{14t'}{9}$	$\frac{D}{9R}-\frac{15t'}{3}$	$\frac{D}{9R}-\frac{16t'}{9}$
9R	$\frac{D}{9R}$-t′	$\frac{D}{9R}-\frac{10t'}{9}$	$\frac{D}{9R}-\frac{11t'}{9}$	$\frac{D}{9R}-\frac{4t'}{3}$	$\frac{D}{9R}-\frac{13t'}{9}$	$\frac{D}{9R}-\frac{14t'}{9}$	$\frac{D}{9R}-\frac{15t'}{3}$	$\frac{D}{9R}-\frac{16t'}{9}$
10R	$\frac{D}{10R}-\frac{9t'}{10}$	$\frac{D}{10R}$-t′	$\frac{D}{10R}-\frac{11t'}{10}$	$\frac{D}{10R}-\frac{6t'}{5}$	$\frac{D}{10R}-\frac{13t'}{10}$	$\frac{D}{10R}-\frac{7t'}{5}$	$\frac{D}{10R}-\frac{3t'}{2}$	$\frac{D}{10R}-\frac{8t'}{5}$
11R	$\frac{D}{11R}-\frac{9t'}{11}$	$\frac{D}{11R}-\frac{10t'}{11}$	$\frac{D}{11R}$-t′	$\frac{D}{11R}-\frac{12t'}{11}$	$\frac{D}{11R}-\frac{13t'}{11}$	$\frac{D}{11R}-\frac{14t'}{11}$	$\frac{D}{11R}-\frac{15t'}{11}$	$\frac{D}{11R}-\frac{16t'}{11}$
12R	$\frac{D}{12R}-\frac{3t'}{4}$	$\frac{D}{12R}-\frac{5t'}{6}$	$\frac{D}{12R}-\frac{11t'}{12}$	$\frac{D}{12R}$-t′	$\frac{D}{12R}-\frac{13t'}{12}$	$\frac{D}{12R}-\frac{7t'}{6}$	$\frac{D}{12R}-\frac{5t'}{4}$	$\frac{D}{12R}-\frac{4t'}{3}$
13R	$\frac{D}{13R}-\frac{9t'}{13}$	$\frac{D}{13R}-\frac{10t'}{13}$	$\frac{D}{13R}-\frac{11t'}{13}$	$\frac{D}{13R}-\frac{12t'}{13}$	$\frac{D}{13R}$-t′	$\frac{D}{13R}-\frac{14t'}{13}$	$\frac{D}{13R}-\frac{15t'}{13}$	$\frac{D}{13R}-\frac{16t'}{13}$
14R	$\frac{D}{14R}-\frac{9t'}{14}$	$\frac{D}{14R}-\frac{5t'}{7}$	$\frac{D}{14R}-\frac{11t'}{14}$	$\frac{D}{14R}-\frac{6t'}{7}$	$\frac{D}{14R}-\frac{13t'}{14}$	$\frac{D}{14R}$-t′	$\frac{D}{14R}-\frac{15t'}{14}$	$\frac{D}{14R}-\frac{8t'}{7}$
15R	$\frac{D}{15R}-\frac{3t'}{5}$	$\frac{D}{15R}-\frac{10t'}{15}$	$\frac{D}{15R}-\frac{11t'}{15}$	$\frac{D}{15R}-\frac{4t'}{5}$	$\frac{D}{15R}-\frac{13t'}{15}$	$\frac{D}{15R}-\frac{14t'}{15}$	$\frac{D}{15R}$-t′	$\frac{D}{15R}-\frac{16t'}{15}$
16R	$\frac{D}{16R}-\frac{9t'}{16}$	$\frac{D}{16R}-\frac{10t'}{16}$	$\frac{D}{16R}-\frac{11t'}{16}$	$\frac{D}{16R}-\frac{3t'}{4}$	$\frac{D}{16R}-\frac{13t'}{16}$	$\frac{D}{16R}-\frac{7t'}{8}$	$\frac{D}{16R}-\frac{15t'}{16}$	$\frac{D}{16R}$-t′

Table 2 Reduced or extended time after transferring data of amount D in another rate channel

	R	2R	3R	4R	5R	6R	7R	8R	9R	10R	11R	12R	13R	14R	15R	16R
R	0	$-\frac{1D}{2R}$	$-\frac{2D}{3R}$	$-\frac{3D}{4R}$	$-\frac{4D}{5R}$	$-\frac{5D}{6R}$	$-\frac{6D}{7R}$	$-\frac{7D}{8R}$	$-\frac{8D}{9R}$	$-\frac{9D}{10R}$	$-\frac{10D}{11R}$	$-\frac{11D}{12R}$	$-\frac{12D}{13R}$	$-\frac{13D}{14R}$	$-\frac{14D}{15R}$	$-\frac{15D}{16R}$
2R	$\frac{1D}{2R}$	0	$-\frac{1D}{6R}$	$-\frac{1D}{4R}$	$-\frac{3D}{10R}$	$-\frac{1D}{3R}$	$-\frac{5D}{14R}$	$-\frac{3D}{8R}$	$-\frac{7D}{18R}$	$-\frac{2D}{5R}$	$-\frac{9D}{22R}$	$-\frac{5D}{12R}$	$-\frac{11D}{26R}$	$-\frac{3D}{7R}$	$-\frac{13D}{30R}$	$-\frac{7D}{16R}$
3R	$\frac{2D}{3R}$	$\frac{1D}{6R}$	0	$-\frac{1D}{12R}$	$-\frac{2D}{15R}$	$-\frac{1D}{6R}$	$-\frac{4D}{21R}$	$-\frac{5D}{24R}$	$-\frac{6D}{27R}$	$-\frac{7D}{30R}$	$-\frac{8D}{33R}$	$-\frac{1D}{4R}$	$-\frac{10D}{39R}$	$-\frac{11D}{42R}$	$-\frac{12D}{45R}$	$-\frac{13D}{48R}$
4R	$\frac{3D}{4R}$	$\frac{1D}{4R}$	$\frac{1D}{12R}$	0	$-\frac{1D}{20R}$	$-\frac{1D}{12R}$	$-\frac{3D}{28R}$	$-\frac{1D}{8R}$	$-\frac{5D}{36R}$	$-\frac{3D}{20R}$	$-\frac{7D}{44R}$	$-\frac{1D}{6R}$	$-\frac{9D}{52R}$	$-\frac{5D}{28R}$	$-\frac{11D}{56R}$	$-\frac{1D}{5R}$
5R	$\frac{4D}{5R}$	$\frac{3D}{10R}$	$\frac{2D}{15R}$	$\frac{1D}{20R}$	0	$-\frac{1D}{30R}$	$-\frac{2D}{35R}$	$-\frac{3D}{40R}$	$-\frac{4D}{45R}$	$-\frac{1D}{10R}$	$-\frac{6D}{55R}$	$-\frac{7D}{60R}$	$-\frac{8D}{65R}$	$-\frac{9D}{70R}$	$-\frac{2D}{15R}$	$-\frac{11D}{80R}$
6R	$\frac{5D}{6R}$	$\frac{1D}{3R}$	$\frac{1D}{6R}$	$\frac{1D}{12R}$	$\frac{1D}{30R}$	0	$-\frac{1D}{42R}$	$-\frac{1D}{24R}$	$-\frac{1D}{18R}$	$-\frac{1D}{15R}$	$-\frac{5D}{66R}$	$-\frac{1D}{12R}$	$-\frac{7D}{78R}$	$-\frac{2D}{21R}$	$-\frac{1D}{10R}$	$-\frac{5D}{48R}$
7R	$\frac{6D}{7R}$	$\frac{5D}{14R}$	$\frac{4D}{21R}$	$\frac{1D}{8R}$	$\frac{3D}{40R}$	$\frac{1D}{24R}$	0	$-\frac{1D}{56R}$	$-\frac{2D}{63R}$	$-\frac{3D}{70R}$	$-\frac{4D}{77R}$	$-\frac{5D}{84R}$	$-\frac{6D}{91R}$	$-\frac{7D}{98R}$	$-\frac{8D}{105R}$	$-\frac{9D}{112R}$
8R	$\frac{7D}{8R}$	$\frac{3D}{8R}$	$\frac{5D}{24R}$	$\frac{1D}{8R}$	$\frac{3D}{40R}$	$\frac{1D}{24R}$	$\frac{1D}{56R}$	0	$-\frac{1D}{72R}$	$-\frac{1D}{40R}$	$-\frac{3D}{88R}$	$-\frac{1D}{24R}$	$-\frac{5D}{104R}$	$-\frac{3D}{56R}$	$-\frac{7D}{120R}$	$-\frac{1D}{16R}$
9R	$\frac{8D}{9R}$	$\frac{7D}{18R}$	$\frac{6D}{27R}$	$\frac{5D}{36R}$	$\frac{4D}{45}\frac{D}{R}$	$\frac{1D}{18R}$	$\frac{2D}{63}\frac{D}{R}$	$\frac{1D}{72R}$	0	$-\frac{1D}{90R}$	$-\frac{2D}{99R}$	$-\frac{1D}{36R}$	$-\frac{4D}{117R}$	$-\frac{5D}{126R}$	$-\frac{2D}{45R}$	$-\frac{7D}{144R}$
10R	$\frac{9D}{10R}$	$\frac{2D}{5R}$	$\frac{7D}{30R}$	$\frac{3D}{20R}$	$\frac{1D}{10R}$	$\frac{1D}{15R}$	$\frac{3D}{70R}$	$\frac{1D}{40R}$	$\frac{1D}{90R}$	0	$-\frac{1D}{110R}$	$-\frac{1D}{60R}$	$-\frac{3D}{130R}$	$-\frac{1D}{35R}$	$-\frac{1D}{30R}$	$-\frac{3D}{80R}$
11R	$\frac{10D}{11R}$	$\frac{9D}{22R}$	$\frac{8D}{33R}$	$\frac{7D}{44R}$	$\frac{6D}{55R}$	$\frac{5D}{66R}$	$\frac{4D}{77R}$	$\frac{3D}{88R}$	$\frac{2D}{99R}$	$\frac{1D}{110R}$	0	$-\frac{1D}{132R}$	$-\frac{2D}{143R}$	$-\frac{3D}{154R}$	$-\frac{4D}{165R}$	$-\frac{5D}{176R}$
12R	$\frac{11D}{12R}$	$\frac{5D}{12R}$	$\frac{1D}{4R}$	$\frac{1D}{6R}$	$\frac{7D}{60R}$	$\frac{1D}{12R}$	$\frac{5D}{84R}$	$\frac{1D}{24R}$	$\frac{1D}{36R}$	$\frac{1D}{60R}$	$\frac{1D}{132R}$	0	$-\frac{1D}{156R}$	$-\frac{1D}{84R}$	$-\frac{1D}{60R}$	$-\frac{1D}{48R}$
13R	$\frac{12D}{13R}$	$\frac{11D}{26R}$	$\frac{10D}{39R}$	$\frac{9D}{52R}$	$\frac{8D}{65R}$	$\frac{7D}{78R}$	$\frac{6D}{91R}$	$\frac{5D}{104R}$	$\frac{4D}{117R}$	$\frac{3D}{130R}$	$\frac{2D}{143R}$	$\frac{2D}{143R}$	0	$-\frac{1D}{182R}$	$-\frac{2D}{195R}$	$-\frac{3D}{208R}$
14R	$\frac{13D}{14R}$	$\frac{3D}{7R}$	$\frac{11D}{42R}$	$\frac{5D}{28R}$	$\frac{9}{70R}$	$\frac{2D}{21R}$	$\frac{7}{98R}$	$\frac{3D}{56R}$	$\frac{5}{126R}$	$\frac{1D}{35R}$	$\frac{3}{154R}$	$\frac{1D}{84R}$	$\frac{1D}{182R}$	0	$-\frac{1D}{210R}$	$-\frac{1D}{112R}$
15R	$\frac{14D}{15R}$	$\frac{13D}{30R}$	$\frac{12D}{45R}$	$\frac{11D}{56R}$	$\frac{2D}{15R}$	$\frac{1D}{10R}$	$\frac{8D}{105R}$	$\frac{7D}{120R}$	$\frac{2D}{45R}$	$\frac{1D}{30R}$	$\frac{4D}{165R}$	$\frac{1D}{60R}$	$\frac{2D}{195R}$	$\frac{1D}{210R}$	0	$-\frac{1D}{240R}$
16R	$\frac{15D}{16R}$	$\frac{7D}{16R}$	$\frac{13D}{48R}$	$\frac{1D}{5R}$	$\frac{11D}{80R}$	$\frac{5D}{48R}$	$\frac{9D}{112R}$	$\frac{1D}{16R}$	$\frac{7D}{144R}$	$\frac{3D}{80R}$	$\frac{5D}{176R}$	$\frac{1D}{48R}$	$\frac{3D}{208R}$	$\frac{1D}{112R}$	$\frac{1D}{240R}$	0

(-ve for time reduced or saved, +ve for time increased or extended)

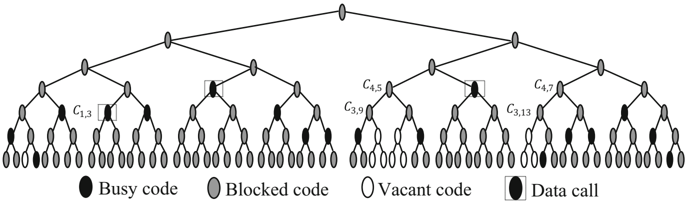

Fig. 4 Example for multi code assignment scheme

Let capacity of calls in buffer is $\gamma^B = 4R \leq \gamma^B_{max}$ and a call of $16R$ ends using capacity of code $C_{5,4}$ and a new data call of rate $5R$ capacity arrives for Fig. 3. The status of code tree after $16R$ ends is as shown in Fig. 3. The total capacity required to handle data calls in buffer with new call request will be $9R$. This capacity is assigned to code $C_{5,4}$, these calls are handled at a faster rate utilizing the unused capacity of the tree and for most of the calls it will compensate time calls spent in buffer waiting them to be handled. The effect on call duration when a data call is assigned to code of different rate (higher /lower) is calculated in Tables 1 and 2.

2.3 Multi Code Improvement

If a single code is not available to handle rate of requested call and $\gamma^{Un}_{L,n_L} + 2^{l-1}R \leq 2^{L-1}R$, multi codes can be used to reduce code blocking probability of the system equipped with r rakes.

2.3.1 Quantized Call

For a quantized call request of rate kR, search all vacant or busy codes of rate $2^{l_i-1}R$, where $1 \leq l_i \leq (l-1)$. Find $x(l_i)$, if a tie occurs $i.e.$ more than two codes with $max(l_i)$ available, select code which has $min(\gamma^{Un}_{l',n_{l'}})$, where $l' \geq l_i$ and break requested rate into rate fractions such that $F^i_{rem} = (k-2^{l_i-1})R$ and $\sum_{i=1}^{m\leq r} F^i_{rem} = kR$. The assignment procedure of selecting a code is same as in single code assignment. The value of m should be minimum as it will lead to less scattering when call ends.

2.3.2 Non Quantized Call

For a non quantized call request of rate kR, break call into $m$fractions such that each fraction is quantized for r rake system $i.e$ $\sum_{i=1}^{m\leq r} F^i_{rem} = kR$. For m fractions divide kR, find $l^{k_i} = (log_2 k_i + 1)$ and $F^i_{rem} = (2^{l^{k_i}-1} - k)R | F^i_{rem} = 2^j R$, $j \in [0, 4]$. Converting non quantized calls into quantized fractions will lead to least internal fragmentation when call arrive and depart.

The code assignment for the data calls can be illustrated with code tree Fig. 4. A voice call of rate $3R$ arrives and $\gamma^B = \gamma^B_{max}$, this call is converted into rate fraction of $2R$ and R rates. The candidate code available for $2R$ are $C_{2,18}$, $C_{2,19}$ and $C_{2,25}$ with their first parents $C_{3,9}$, $C_{3,10}$ and $C_{3,13}$.The capacity unutilized $\gamma^{Un}_{3,9}$, $\gamma^{Un}_{3,10}$ and $\gamma^{Un}_{3,13}$ are $2R$, $2R$ and $2R$ respectively. Their second parents $C_{4,5}$ and $C_{4,7}$ with unutilized $\gamma^{Un}_{4,5}$ and $\gamma^{Un}_{4,7}$, $4R$ and $2R$ respectively. The code assigned is $C_{2,25}$. For R rate code $C_{1,3}$ is assigned using LCA.

Table 3 Requested call rate fraction possible and number of rakes

	2 rakes	3 rakes	4 rakes
2R	R, R	–	–
3R	2R, R	R, R, R	–
4R	2R, 2R	2R, R, R	R, R, R, R
5R	4R, R	2R, 2R, R	2R, R, R, R
6R	4R, 2R	2R, 2R, 2R 4R, R, R	2R, 2R, R, R
7R	4R, 3R	4R, 2R, R	2R, 2R, 2R, R 4R, R, R, R
8R	4R, 4R	4R, 2R, 2R	2R, 2R, 2R, 2R 4R, 2R, R, R
9R	8R, R	4R, 4R, R	4R, 2R, 2R, R
10R	8R, 2R	4R, 4R, 2R 8R, R, R	4R, 2R, 2R, 2R 4R, 4R, R, R
11R	8R, 3R	8R, 2R, R	4R, 4R, 2R, R 8R, R, R, R
12R	8R, 4R	4R, 4R, 4R 8R, 2R, 2R	4R, 4R, 2R, 2R 8R, 2R, R, R
13R	8R, 5R	8R, 4R, R	4R, 4R, 4R, R 8R, 2R, 2R, R
14R	8R, 6R	8R, 4R, 2R	4R, 4R, 4R, 2R 8R, 4R, R, R 8R, 2R, 2R, 2R
15R	8R, 7R	8R,4R,3R	8R, 4R, 2R, R
16R	8R, 8R	8R, 4R, 4R	4R, 4R, 4R, 4R 8R, 4R, 2R, 2R

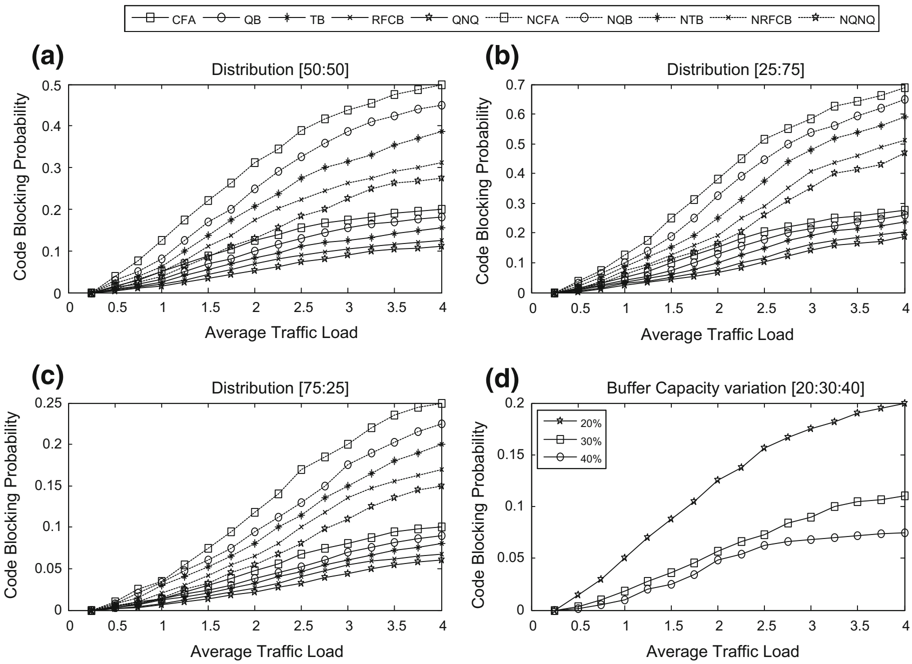

Fig. 5 Comparison of code blocking probability of single code schemes for distribution: **a** uniform;[50:50] ; **b** high rate distribution; [25:75] **c** low rate dominating; [75:25], **d** buffer capacity percentage variation [20:30:40]

The rate request, number of rakes and combination which can be used to handle new call is shown in Table 3.

3 Simulation and Results

The code blocking probability performance of the proposed quantized and non quantized (QNQ) assignments scheme is compared with existing novel schemes in literature. For simulation, five classes of users are considered with rates $R,\ 2R,\ 4R,\ 8R$, and $16R$ respectively. For ith class, the arrival rate is represented by λ_i. Call duration $1/\mu_i$ is exponentially distributed with mean value of one units of time. Define $\rho_i = \lambda_i/\mu_i$ as traffic load of the ith class users, then for five class system the average arrival rate and average traffic load is $\lambda = \sum_{i=1}^{5} \lambda_i$ and $\rho = \sum_{i=1}^{5} \lambda_i/\mu_i$ respectively. The average arrival rate (or average traffic load as $1/\mu_i$ is 1) is assumed to be Poisson distributed with mean value varying from 0–4 calls per unit of time. In this paper for simulation, call duration of all the calls are equal *i.e.* $1/\mu = 1/\mu_i = 1$. Therefore, the average traffic load is $\rho = 1/\mu \times \sum_{i=1}^{5} \lambda_i = \lambda/\mu$. The maximum capacity of the tree is $128R$ (R is $7.5\ kbps$). Simulation is done for 5,000 users and result is average of 25 simulations. Define $[p_1, p_2, p_3, p_4, p_5]$ as capacity distribution matrix, where $p_i,\ i \in [1, 5]$ is the percentage fraction of the total tree capacity used by the ith class users. The traffic load includes five different rates, where $R,\ 2R$ are low rate (assumed) real time calls, and higher rates $4R,\ 8R,\ 16R$ can be considered as non real time calls. Three distribution scenarios are analyzed [Quantized, Non quantized], (1) [50,50], uniform distribution of all rate calls shown by continuous plots and low rate dominating shown by dashed plots, (2) [25,75], uniform distribution of all rate calls shown by continuous plots and high rate dominating shown by dashed plots, (3) [75,25], uniform distribution of all rate calls shown by continuous plots and low rate dominating shown by dashed plots. The proposed call assignment scheme (QNQ) in this paper is compared with crowded first assignment (CFA), quality based (QB) [20], time based (TB) [21] and recursive fewer blocked (RFCB) schemes in literature. The QNQ schemes provides less code blocking probability as compared to these schemes as it separates quantized and non quantized calls before assignment and also differentiates voice and data calls. The call establishment delay of QNQ scheme will also be lesser as compare to these scheme as it searches only half portion of code tree for quantized or non quantized calls for most of the call requests. The plots in Fig. 5 are for system when calls arrive are quantized only shown by uniform line and dashed line when call arrives are both type: quantized and non quantized. The buffer capacity variation also leads to lower code blocking, the comparison of buffer capacity percentage as 20, 30 and 40 % shown in Fig. 5d.

4 Conclusion

Real time calls are delay sensitive, information will be lost if these calls are handled with delay. The scheme proposed in this paper handles voice call (delay sensitive) more efficiently as compared to existing novel schemes in literature and also leads to lesser blocking probability. In addition call establishment time is also reduced for finding a suitable code which can be assigned due to search of code in half portion of code tree for most of the times a call request arrives to a new call. The scheme has ability to counter with current and future demands of higher rate handling keeping the blocking to minimal levels.

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