Code scattering and reduction in OVSF code blocking for 3G and beyond mobile communication systems

NEERU SHARMA, DAVINDER S. SAINI
Department of Electronics and Communication Engineering
Jaypee University of Information Technology
Waknaghat, Distt. Solan.(H.P.) -173215
INDIA
Neeru.sharma@juit.ac.in, davinder.saini@juit.ac.in

Abstract:- Scattered vacant codes in Orthogonal Variable Spreading Factor (OVSF) code based 3G and beyond WCDMA wireless networks leads to code blocking which further gives call blocking. The paper proposes four single code assignment schemes to reduce code scattering. The use of assignment scheme depends upon the type of input calls. The code reservation assignment (CRA) is used to efficiently handle one or higher rate class calls. It assigns priority number to the children of priority class codes such that the future availability of vacant codes in the priority layer is the highest. The remaining three code assignment schemes favors low to medium calls. The code assignment using group leaders uses busy codes (capacity) under predefined leaders to handle future calls. The code blocking in group leader approach can be reduced further if the used capacity of all the parents of the eligible vacant codes is examined and the code whose parent has maximum used capacity is used for new call. In adjacent vacant codes grouping scheme, the eligible vacant codes are listed to find code with least adjacent vacant codes. If unique result does not exists, the code (among the codes producing same adjacent vacant codes) with the least elapsed time of the busy neighbors is used for incoming call.

Key Words:- OVSF codes, code/call blocking, OVSF assignment, OVSF reassignment, OVSF code scattering.

1 Introduction

3G and beyond mobile communication systems use Orthogonal Variable Spreading Factor codes to handle variable data rates in the uplink and downlink. The limited number of OVSF codes in the downlink needs efficient allocation for new calls. The OVSF codes suffer from limitation of internal fragmentation [1] and external fragmentation [1] which leads to OVSF code blocking. The internal fragmentation is due to the quantized rate handling capability of code tree. The external fragmentation is due to the scattered vacant codes in the code tree. The OVSF code blocking in WCDMA reduces the new call handling capability of code tree. The paper proposes compact code assignment schemes to reduce code blocking due to scattered vacant codes.

The remainder of the paper is organized as follows. Section 2 gives OVSF code tree preliminaries. Section 3 describes four proposed code assignment schemes along with the algorithms and examples to demonstrate each code assignment schemes. Section 3 demonstrates results to show the superiority of the code assignment schemes for different distributions. The paper is concluded in section 4.

2 Preliminaries

2.1 OVSF Code Generation and Blocking Property

OVSF based systems such as WCDMA provides have the ability to handle variable user data rates. OVSF codes are treasured by its capability of reducing multiple access interference (MAI) and supporting high rate and variable rate data operation. Spread spectrum [2] is the technique by which OVSF system works efficiently even in noisy environments. This unique quality of OVSF codes spread data to an extent that it represents noise. Spectrum spreading is achieved by conditioning each data bit by an assigned code sequence. The length of the code sequence is called the spreading factor (SF). The OVSF codes can be represented by a complete binary tree called the OVSF code tree. These variable spreading factor codes support different data rates in an OVSF-WCDMA system with only one spreading code per user. The codes at each layer of the tree have different spreading factors, allowing users to transmit at different data rates.

A detailed description of OVSF code generation can be found in [3]. Consider the downlink of an OVSF-WCDMA system with L (L =8 in WCDMA) layers of OVSF code tree. The code in layer $l, l \in [0, L-1]$ is represented by $C_{l,n}$ where $1 \leq n \leq 2^{L-l-1}$. The maximum capacity of each layer and the system is $2^{L-1}R$, R is 7.5 kbps. The total number of codes and SF in layer l is 2^{L-l-1}. The data rate handled by the code in the layer l is $2^{l}R$. There are L different arrival classes of users with data rate R, $2R$,…., $2^{L-1}R$. Some properties of OVSF codes are listed below.

- $C_{l,n}$, $l \in [1,7]$ has two children namely $C_{l-1,2n-1}$ and $C_{l-1,2n}$. Suppose the code sequence of $C_{l,n}$ is [x], then the code sequence of $C_{l-1,2n-1}$ is [x, x] if $C_{l-1,2n-1}$ is the left child of $C_{l,n}$ and code sequence of $C_{l-1,2n}$ is [x, -x] ([-x] is the bitwise complement of [x]) if $C_{l-1,2n-1}$ is the right child of $C_{l,n}$.
- For an L layer OVSF code tree, if the SF of $C_{l,n}$ is 2^{L-l-1}, $l \in [1,7]$, then the SF of $C_{l-1,2n-1}$ or $C_{l-1,2n}$ is 2^{L-l}. Consequently, if the data rate of handled by $C_{l,n}$ is $2^{l}R$, then the data rate of $C_{l-1,2n-1}$ or $C_{l-1,2n}$ is $2^{l-1}R$. Hence leaf nodes are designed to handle minimum data rate and root node is designed to handle maximum data rate.
- If a code is used, then simultaneous use of its descendants or ancestors is not allowed because their encoded sequences are indistinguishable.
- Any two codes of different layers are orthogonal except for the case that one of the two codes is parent of the other. This exception in OVSF codes leads to the *blocking property* which states that, once a code is used in OVSF code tree, all of its ancestors and descendants are blocked. This limitation of code blocking in OVSF codes leads to poor utilization of OVSF tree capacity.

To illustrate code scattering code scattering consider a six layer code tree with maximum capacity of 32 units as shown in Figure 1. There are 8 busy codes in layer 0, 1 busy code in layer1 and 1 busy code in layer 2. The used capacity of the code tree becomes 14 $(8\times1+1\times2+1\times4)$ units. The remaining capacity of the code tree is 32-14=18 units. If a new call requires a code from layer 3 (with capacity 8 units), it finds all four codes $C_{3,0}$, $C_{3,1}$, $C_{3,2}$, and $C_{3,4}$ blocked. So the new call will be rejected due to scattered vacant codes in lower layers.

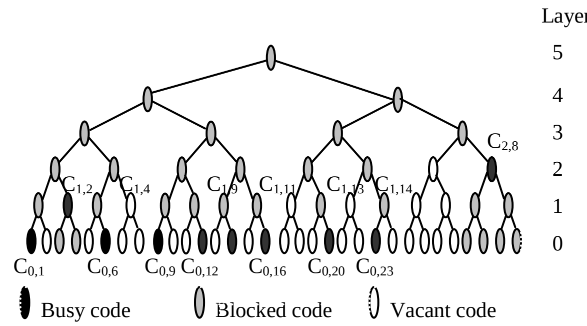

Figure 1 Code tree with capacity of 32 units

2.2 Scattered codes

When a new call arrives requesting for a vacant code with rate kR, $k=2^{l}$ ($l \in [0,L-1]$), it requires a vacant code of similar rate. The codes can be assigned till the capacity of the tree is fully occupied with the constraint that single code should be used per call. For a new incoming call, there is possibility of two situations arising based on the configuration of system. Firstly the capacity is insufficient to serve the call and secondly the capacity is sufficient to serve the call. In the first case, the call is dropped. For the latter case call is blocked due to code scattering.

Scattered codes are those free or unoccupied codes which lie or are distributed in the neighborhood of occupied codes of similar capacity level. They are called scattered in the sense that there distribution at any time in particular capacity level is random. Scattering problem is more pronounced at lower layers in single OVSF code systems. Scattering is present due to following reasons

- Random allocation of codes.
- Different service time of calls.
- Different arrival and departure rate of calls.
- Non-utilization of codes due to frequent fragmentation i.e. external fragmentation.

Scattered codes generally decrease efficiency and throughput of OVSF code tree. Most severely it decreases capacity utilization because scattering induces fragmentation and hence blocking of calls even when sufficient capacity is available. There are probably two most effective ways to cope with this problem

- Reassignment of codes
- Code Management

Under reassignment scheme the overhead and complexity are more. The probability of reassigning more than 2, 3 or more codes/calls for supporting particular incoming call is very high. The frequent reassignments may prove to be more costly and is mostly avoided.

Most suitable method which can appreciably remove scattering of code is code management. Our proposed scheme usually tries to allocate and manage the calls based on making congested part of tree more congested and hence allowing more space for higher rate calls. It focuses on the recollecting behavior and ensures the maximum usage of such scattered codes. The main idea behind our scheme revolves round the compact assignment of such codes based on scattering level and the elapsed time of the already busy codes. The idea is simple and is quite similar to crowded scheme but with a difference that while crowded scheme is based on branch wise compactness, this scheme is based on compactness at particular level.

2.3 Code Assignment and Reassignment Schemes

A number of code assignment schemes are proposed in literature to reduce/eliminate code blocking problem. The code assignment schemes can be categorized into single code [4,5] and multi code [6,7] assignment schemes. The single code assignment scheme uses single code to handle incoming calls. The incoming calls are converted into quantized rates (if not so). The single code assignment schemes are simpler, cost effective and require single rake combiner at the base station (BS)/user equipment (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 are higher. In the leftmost code assignment (LCA) [8] scheme, the code assignment is done from the left side of the code tree. In random assignment (RA) [8] scheme, any of the vacant code is picked randomly to handle new call. LCA and RA schemes suffer from the limitation of large blocking probability and smaller throughput. Crowded first assignment scheme (CFA) [8] uses the crowded portion of the tree for code assignment. The time code (TC) assignment scheme in [9] uses remaining time of the call to make code tree less fragmented. The ancestor code assignment scheme proposed in our research works on top of [8] with two additions (a) number of busy codes under ancestors of candidate codes (b) elapsed time of ongoing calls under the ancestors of busy codes. The fewer codes blocked (FCB) scheme in [10] use the number of new codes blocked for ancestors of vacant codes and then solve ties using level of the ancestors. In dynamic code assignment (DCA) [11] 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 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. 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 defines 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 sharing scheme in [16] handles non quantized rates efficiently and leads to reduction in code blocking. . The multi code design in [17] finds the most suitable multi code combination required for a new call. The symbols used in the paper are given in Table 1.

Table 1 Symbols used

Symbol	Meaning
$C_{x,y}$, $P_{x,y}$	y_{th} code in layer x, priority of code y in layer x
C_{max}	maximum capacity of the OVSF code tree
λ, λ_k	mean arrival rate of the system, arrival rate of k_{th} class
μ, μ_k	mean service rate of the system, service rate of k_{th} class
ρ, ρ_k	average traffic load= λ / μ , k_{th} class traffic load= λ_k / μ_k
$VC_{x,a_i}, i \in [1,m]$	vacant candidate code a_i to handle new call
$P^y VC_{x,a_i}, i \in [1,m]$	parent of the code VC_{x,a_i} in y_{th} layer
$N^y VC_{x,a_i}, i \in [1, n_{x+1}]$	number of busy children for the code $P^y VC_{x,a_i}, i \in [1,m]$
G, G_k	number of vacant codes in the OVSF code tree represented by G={G_1,G_2,G_3,G_4,G_5,G_6, G_7,G_8},number of vacant codes in k_{th} class
P_{B_k}, P_B,	code blocking probability in k_{th} class, average blocking probability

3 Compact Code Assignment Schemes

3.1 Code reservation assignment (CRA) scheme

Define $P_{x,y}$ as the priority number signifying priority of the code y in layer x. Let the users with rate $2^m R$, $m \in [1,L\text{-}2]$ be given higher priority. The value of m depends on the application network (e.g. real time video conferencing may require layers 5 or 6 and internet data may also require one or more layers close to root). The CRA schemes assign priority to all the vacant codes in the layers 0 to m-1 (with rates R to $2^{m-1}R$). When a new user with rate $2^p R$, $p\in[0,m\text{-}1]$ arrives, the vacant code is assigned to user and some its relatives will be assigned priority such that future probability of priority class codes is highest. For the layers 1 to m-1, the vacant codes with highest priority number are the candidates to handle new call. For a newly occupied code $C_{p,x}$, group of codes blocked (G_B) in the OVSF code tree are given by

$$G_B = \begin{cases} C_{i,2^{p-i}(x-1)+1} \ldots . C_{i,2^{p-i}x}; & 0 \le i \le p \\ C_{i,\left\lceil \frac{x}{2^{i-p}} \right\rceil}; & p \le i \le L \end{cases} \quad (1)$$

Define $y = \left\lceil \frac{x}{2^{m-p}} \right\rceil$. The group of total codes (G_T) which are the children of code $C_{m,y}$ in the layer m ($C_{m,y}$ should also be the parent of $C_{p,x}$) are given by

$$G_T = C_{j,2^{m-j}(y-1)+1} .. C_{j,2^{m-j}y}; 0 \le j \le m \quad (2)$$

If the entire children codes under the code $C_{m,y}$ are vacant prior to new call, the group of codes which are assigned priority number (G_P) are

$$G_P = G_T\text{-}G_B\text{-}C_{p,x} \quad (3)$$

As given in Equation (3), the relatives of the code $C_{p,x}$ having capacity less than $2^{m-1}R$ are candidates for higher priority. The priority numbers are valid only for codes in layers 1 to m. If the entire children codes under the code $C_{m,y}$ are not vacant prior to new call, the group of codes which are assigned priority number (G_P) are given by

$$G_P = G_T\text{-}G_B\text{-}G_O\text{-}C_{p,x} \quad (4)$$

where G_O is the sum of all the occupied (busy) codes under $C_{m,y}$. The procedure is repeated for every new call. So, the assignment scheme chooses the vacant code for non priority calls whose busy brother (s) has the latest arrival. This is done to provide priority class layer with most number of vacant codes. Therefore OVSF code tree scattering is intentionally increased at the beginning of code assignment for better handling of priority class users. This is exactly what was not done in previous compact code assignment schemes. We divide the codes in OVSF code tree in three groups.

- Non priority class codes in layer 0 to m-1.
- Priority class codes in layer m.
- Non priority class codes in layer m+1 to L.

The code priority in above three categories has the following properties for code assignment and code vacation.

(a) Non priority class codes in layer 0 *to* m-1

When a code is assigned to the new call, the vacant codes which are the children of m^{th} layer parent of the assigned code are assigned priority higher than the highest current value. When the existing busy code becomes vacant, all the relative codes and blocked codes in layers 0 to m-1 are given priority equal to the highest priority value under the m^{th} layer parent.

(b) Codes in priority class in layer m

When a code is assigned to the new call, none of the codes are given priority. When the codes are vacated, the codes in layer 0 to m-1 which are the children of assigned code are given priority less than the lowest priority in layer 0 to m-1. No priority is given to the codes in layer m to L.

*(c) Non-priority class codes in layer m+*1 *to L*

When a code is assigned in this group, priority number in any layer is not affected. When the codes are vacated, the codes in layer 0 to m which are the children of vacated code are given priority less than the least priority number.

Define a_x, t_{arr}, λ (equal to $1/t_{arr}$) as number of busy codes in layer x, inter arrival time, arrival rate of users. The priority number is refreshed after every t_r (threshold time) units of time, where $t_r > kt_{arr}$, $1<k<N$, $N<(a_0+2a_1+4a_2+..128a_7)$. The priority number is also refreshed after every call completion and call arrival.

The code assignment scheme is illustrated in Figure 2 for an OVSF-CDMA system with maximum capacity of 32R. The codes in layer 3 (corresponding to 8R users) are given highest priority. Initially the code tree is assumed to be completely unused. Let a new call with rate 4R is allocated a code $C_{2,1}$. The code assignment, code blocking and code reservation for future calls is shown in Figure 2(a). All the relatives encircled are given priority number 1. For second 2R call, the code is searched which do not have any priority number assigned. Starting from left code $C_{1,21}$ is used and all its relatives are given priority number 1 (as shown in Figure 2(a)). The priority number of codes in the layer of each relative which already has priority number is incremented by 1. In the example considered such codes are $C_{2,1}$, $C_{1,3}$, $C_{1,4}$, $C_{0,5}$, $C_{0,6}$, $C_{0,7}$, and $C_{0,8}$. There new priority number becomes 2 (as represented in Figure 2(b). The codes $C_{2,1}$, $C_{1,5}$, $C_{0,17}$ and $C_{4,3}$ are codes used for new calls. For next calls R and 2R using codes $C_{0,17}$ and $C_{1,13}$, the priority number assignment is shown in Figure (c). Now considering status in Figure 2(c), if a new 4R call arrives, the highest priority code $C_{2,11}$ will be used.

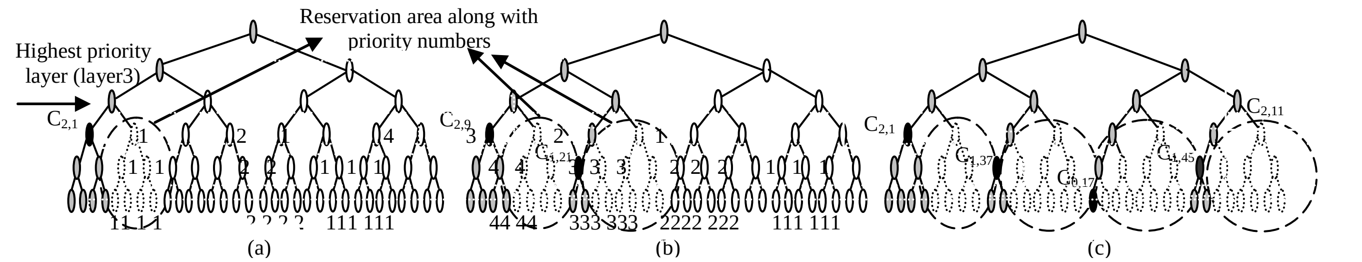

Figure 2 Illustration of code reservation scheme

In case, the priorities need to be set for more than one class (say *c* classes), the *L* layer code tree is divided into *c* groups. Each group belongs to one of the *c* priority classes. The algorithm for the CRA scheme is shown below.

1. Enter arrival rate, service time, data rates, number of groups, priority class layer(s)
2. Generate new call with rate kR, $k=2^l$ and $l \in [0,7]$
3. If (C_{used}+rate of incoming call) < C_{max}

- *Do code allocation, code blocking and assignment of priority numbers according to the Equations (1-4)*
- *Change the priority of codes in the code tree*
- *Go to step 2*

Else
Discard call
End
4. if (elapsed time<threshold time)

- *Refresh the priority number*

5. Go to step2

3.2 Code assignment using group leaders (GL)

In group leader approach, we divide the leaves of the code tree into 2^{N-q-1} groups, where $q \in [0,q_{max}]$ and $q_{max} < N$. There are 2^{N-q-1} group leaders in layer *q*. For a group leader $C_{x,y}$, define *used capacity* as sum of capacities of all the children of $C_{x,y}$. The capacity of each group and the group leader is 2^q. For a code $C_{x,y}$, the group leader is $C_{q_{\max},\left\lceil \frac{y}{2^{q_{\max}}-x} \right\rceil}$. For a code $C_{q_{\max},n}$, the codes in the group are given by

$$C = C_{q,2^{q_{\max}-q+1}n-2^{q_{\max}-q+1}n+1},..,C_{q,2^{q_{\max}-q+1}n}$$

$$0<q<q_{max} \qquad (5)$$

Lesser is the value of *q*, more is the number of groups making code tree compact for assignment of low data rates. The division is performed to make the code assignment most compact. The algorithm for assignment scheme is given below,

1. Enter arrival rate, service time, data rates, number of groups
2. Generate new call
3. If (C_{used}+rate of incoming call) < C_{max}

- *List all the vacant codes*
- *For all the vacant codes, find the used capacities of group leaders. The vacant code whose group leader has highest used capacity is the candidate for handling new call. If two or more vacant code leaders has same amount of used capacity, anyone can be used for code assignment*

Else
Discard call
End
4. Go to step2

The above procedure gives reduction in external fragmentation of the remaining capacity making the code assignment compact. The code assignment in layers above group leader's layer (e.g. rates corresponding to layer 5, 6 and 7 in 8 code group example) can be done like LCA and RA schemes.

For illustration consider code tree in Figure 1 where layer 3 codes are can be treated as group leaders. If a new user with requirement of layer 1 code arrives, there are a large number of vacant code options. The vacant code $C_{1,4}$ has a capacity of 4R (sum of capacities of busy codes $C_{0,1}$, $C_{1,2}$ and $C_{0,6}$) under its group leader $C_{3,1}$. Similarly vacant codes $C_{1,9}$, $C_{1,11}$ has a capacity of 2R (sum of the capacities of busy codes $C_{0,20}$ and $C_{0,23}$) under its group leader $C_{3,3}$ and vacant codes $C_{1,13}$, $C_{1,14}$ has a capacity of 4R (capacities of busy code $C_{2,8}$) under its group leader $C_{3,3}$. The group leader capacity of $C_{1,4}$, $C_{1,3}$ and $C_{1,14}$ is maximum and any of the two can be assigned to the incoming call.

3.3 Code assignment using aggregate capacity under ancestors of eligible vacant codes

It is the most compact assignment scheme. The idea is to choose a vacant code such that the availability of higher layer codes after code assignment is maximized. For a code $C_{x,y}$, define *used capacity* as sum of capacities of all the children of $C_{x,y}$. Consider that a new call with the requirement of vacant code in layer x arrives. The algorithm of code assignment is divided into following steps.

1. List all n vacant codes VC_{x,a_i}, where $i \in [1, n_x]$, $1 \le p_i \le 2^{L-x-1}$ in layer x. For each vacant code, calculate the used capacities of first parent $P^{x+1}VC_{x,a_i}, i \in [1, n_{x+1}]$ in layer x+1 where $\lceil n_x/2 \rceil \le n_{x+1} \le n_x$. If there exist a unique parent $P^{x+1}VC_{x,a_i}$ with the maximum used capacity, the code VC_{x,a_i} is the candidate to handle new call. If no unique parent with maximum used capacity exists in layer x+1, calculate the *used capacities* of all the parents $P^{x+2}VC_{x,a_i}, i \in [1, n_{x+2}]$ in layer x+2 where $\lceil n_{x+1}/2 \rceil \le n_{x+2} \le n_{x+1}$. Repeat the procedure for parents $P^{j}VC_{x,a_i}, i \in [1, n_j]$ where $\lceil n_{j-1}/2 \rceil \le n_j \le n_{j-1}$ for all $j \in [x+1, 7]$ till unique parent exists.
2. If no unique parent exists with maximum used capacity in step 1, list all the parents in the layer x+1 given by $P^{x+1}VC_{x,a_i}, i \in [1, n'_{x+1}]$, $n'_{x+1} \le n_{x+1}$ with same maximum used capacity from the set $P^{x+1}VC_{x,a_i}, i \in [1, n_{x+1}]$. For all such parents, list number of busy children in layer 1 to x denoted by $N^{x+1}VC_{x,a_i}, i \in [1, n'_{x+1}]$. The parent $P^{x+1}VC_{x,a_i}$ with the maximum number of busy children is the candidate to handle new call. This results in assigning most scattered portion of the code tree to handle new call giving highest number of vacant codes for future high rate calls. If all the parents $P^{x+1}VC_{x,a_i}, i \in [1, n'_{x+1}]$ have same number of busy children, go to layer x+2 and so on till we reach layer 8.
3. If both above steps leads to more than one parent, for all the parents in layer x+1 $P^{x+1}VC_{x,a_i}, i \in [1, n'_{x+1}]$, find the parent with most number of busy codes in layer 1. If unique parent exists, it is the candidate to handle new call. Otherwise check the parents $P^{j}VC_{x,a_i}, j \in [x+2, 8]$ *and* $i \in [1, n'_j]$ till unique parent exists.
4. If still no unique result exists, check the parents satisfying $P^{j}VC_{x,a_i}, j \in [x+1, 8]$ *and* $i \in [1, n'_j]$ for most number of busy codes. If unique parent exists, the code VC_{x,a_i} is the candidate for handling new call. If all the three steps do not give unique result, list the vacant codes from the set $VC_{x,a_i}, i \in [1, n]$ whose ancestors have busy codes with least average elapsed time. It uses the fact that the code with least elapsed time will be vacated in the end. This increases the availability of higher layer codes for future calls.

For a code $C_{a,b}$, let the parent exist in layer x with branch number y denoted by $C_{x,y}$. Define scattering index $S(x,y)$

$$S(x,y) = \sum_{k=1}^{x-1}\sum_{l=1}^{m_k} VC_{k,l} \tag{6}$$

Scattering index is a measure of number of busy codes under the parent $C_{x,y}$ who is parent of $C_{a,b}$

The algorithm of the code assignment scheme is given below.

1. Enter arrival rate, service time, data rates, number of groups
2. Generate new call
3. If (C_{used}+rate of incoming call) < C_{max}

- *List all vacant codes* $VC_{x,a_i}, i \in [1, n]$
- *Find the suitable codes using the steps 1 to 4*
- *Do code assignment and blocking*

Else
Discard call
End
4. Go to step 2

To illustrate the ancestor cost assignment scheme, consider tree in Figure 1 with new 2R rate arrival. There are five vacant code options. While checking the first parent of vacant codes, capacity tie occurs for codes $C_{1,4}$, $C_{1,9}$ and $C_{1,11}$ (with first parent $C_{2,2}$, $C_{2,5}$ and $C_{2,6}$). If first parent is used for optimization, check the elapsed time of busy codes under $C_{2,2}$, $C_{2,5}$ and $C_{2,6}$ i.e. codes $C_{0,6}$, $C_{0,20}$ and $C_{0,23}$. If the elapsed time of $C_{0,6}$, $C_{0,20}$ and $C_{0,23}$ is 4, 2, 3 units of time, code $C_{1,9}$ is picked for new call because probability of its parent remain blocked for longer time is highest (due to least elapsed time of $C_{0,20}$). If second parent of the candidate vacant codes are used for optimization, capacity tie occurs for parents of candidate codes $C_{1,4}$, $C_{1,13}$ and $C_{1,14}$. The vacant code $C_{1,4}$ is used for new call as its second parent has more number of busy leaves.

3.4 Grouping adjacent vacant codes

The scattered vacant codes at a particular time are known to BS and UE. Mostly the scattered codes in the levels are those vacant codes which lie between the busy nodes and are less in number. The probability of finding more consecutive vacant codes is always less than the probability of one or few vacant codes. The vacant codes which appear in groups are not assigned to the new call because there vacant parents can be used for users with higher rates. Therefore code assignment is done to use the vacant codes which do not appear in groups.

Define $S(l,b,n)$ as a group of codes in layer l accommodating all b, $1 \le b \le 2^{8-l}$ adjacent vacant codes. Also n gives the vacant code number with b adjacent vacant codes. When system finds a vacant code, it checks for the consecutive single vacant code in its vicinity on either side of the vacant code. After finding single adjacent vacant code, the adjacent codes in group of three (2^2-1), seven (2^3-1) and so on up to 2^{7-l}-1 are checked. Index $S(i,b,n)$ is a measure of scattering in the OVSF code tree. Lesser is the value of b, more is the vacant code scattering and new call pick the code with least adjacent vacant codes. For a code $C_{x,y}$, the adjacent vacant codes are

$C_{x,2[((y+1)/2)-1]+1} \ldots C_{x,2[(y+1)/2]}$, for one simultaneous adjacency (7)

$C_{x,4[((y+3)/4)-1]+1} \ldots C_{x,4[(y+3)/4]}$, for three simultaneous adjacencies (8)

The result can be generalized as

$C_{x,N[((y+N-1)/N)-1]+1} \ldots C_{x,N[(y+N-1)/N]}$, for other N=1, 3, 7, 15 etc. (9)

Table 2 illustration of code selection using adjacent vacant code grouping scheme

(a) Group S (0, b, n), R rate call

Adjacencies	Vacant codes	Neighbor/ Elapsed time	Code id
b=0, Single vacant code (no adjacent vacant code)	$C_{0,2}$	$C_{0,1}$/15	S(0,0,1)
	$C_{0,5}$	$C_{0,6}$/15	S(0,0,2)
	$C_{0,10}$	$C_{0,9}$/10	S(0,0,3)
	$C_{0,11}$	$C_{0,12}$/10	S(0,0,4)
	$C_{0,13}$	$C_{0,14}$/7	S(0,0,5)
	$C_{0,15}$	$C_{0,16}$/2	S(0,0,6)
	$C_{0,19}$	$C_{0,20}$/5	S(0,0,7)
	$C_{0,24}$	$C_{0,23}$/5	S(0,0,8)
b=1,Two consecutive vacant codes	$C_{0,7}$	$C_{0,6}$/15	S(0,1,1)
	$C_{0,8}$	$C_{0,6}$/15	S(0,1,2)
	$C_{0,17}$	$C_{0,20}$/5	S(0,1,3)
	$C_{0,18}$	$C_{0,20}$/5	S(0,1,4)
	$C_{0,21}$	$C_{0,23}$/5	S(0,1,5)
	$C_{0,22}$	$C_{0,23}$/5	S(0,1,6)
b=3,Four consecutive vacant codes	$C_{0,25}$	$C_{0,29}$/10	S(0,3,1)
	$C_{0,26}$	$C_{0,29}$/10	S(0,3,2)
	$C_{0,27}$	$C_{0,29}$/10	S(0,3,3)
	$C_{0,28}$	$C_{0,29}$/10	S(0,3,4)

(b) Group S (1, b, n), 2R rate call

Adjacencies	Vacant codes	Neighbor/ Elapsed time	Code id
b=0, Single vacant code	$C_{1,4}$	$C_{1,3}$/15	S(1,0,1)
	$C_{1,9}$	$C_{1,10}$/5	S(1,0,2)
	$C_{1,11}$	$C_{1,12}$/5	S(1,0,3)
b=1, Two consecutive vacant codes	$C_{1,13}$	$C_{1,15}$/10	S(1,1,4)
	$C_{1,14}$	$C_{1,15}$/10	S(1,1,5)

Basically, the code assignment design is divided into two steps

- Group all vacant codes according to adjacent vacant neighbors. Pick the group code with the minimum adjacent vacant codes. If tie occurs go to step 2.
- From all the candidate codes in group found in step 1, pick the vacant code with least elapsed time of busy neighbors. If tie occurs for elapsed times, any code with same least elapsed time is selected.

Let us deploy the above technique for allotment of codes to incoming rate R and 2R in Figure 1. The busy codes are marked with dark shade while blocked codes are gray in color. No color indicated vacant codes. The codes are demarked with there designation and the elapsed duration in units. The elapsed duration for blocked codes is derived based on the highest elapsed duration of the busy codes under it or of its ancestors.

Searching algorithm is employed for finding the codes with various adjacencies i.e. for various values of b and is grouped under group $S(l,b,n)$ where l is level, b are number of adjacencies and n is the total no of codes with same adjacencies. The algorithm of the code assignment scheme is given below.

1. Enter arrival rate, service time, data rates, number of groups
2. Generate new call
3. If (C_{used}+rate of incoming call) < C_{max}

- *Arrange all the vacant candidate codes into groups S(l,b,n) , $l \in [0,7]$. Pick S(l,j,n), j=min(b)*
- *If Single vacant code available in S(i,j,n)*
    - *Assign code to the new call*
- *Else*
    - *Pick the vacant code with least elapsed time of busy neighbors as explained in section 3*
    - *Go to step 2*

Else
Discard call
End
4. Go to step 2

For incoming rate R searching algorithm depicts that there are eight codes possible with adjacent zero vacant codes given by $C_{0,2}$, $C_{0,5}$, $C_{0,10}$, $C_{0,11}$, $C_{0,13}$, $C_{0,15}$, $C_{0,19}$ and $C_{0,24}$. From within these eight codes the code which has lowest elapsed time of its neighbor is selected. The elapsed times for busy codes at new arrival are illustrated in Table 2. The neighbor for any code is the code which comes under same parent as we go up the branch in OVSF tree. The neighbor who is adjacent but under different parent node is not considered for comparison of the elapsed time. Neighbor/elapsed_time(in time units) for $C_{0,2}$, $C_{0,5}$, $C_{0,10}$, $C_{0,11}$, $C_{0,13}$, $C_{0,15}$, $C_{0,19}$ and $C_{0,24}$ are $C_{0,1}$/15, $C_{0,6}$/15, $C_{0,9}$/10, $C_{0,12}$/10, $C_{0,14}$/7, $C_{0,16}$/2, $C_{0,20}$/5 and $C_{0,23}$/5 respectively. These eight entries are designated in group $S(l,b,n)$ as $S(1,0,1)$, $S(1,0,2)$, and so on to $S(1,0,8)$. Since $S(1,0,6)$ have the having least elapsed time so this code is selected for accommodating new R rate call.

Similarly for same scenario and incoming rate of $2R$, the searching algorithm finds vacant codes $C_{1,4}$, $C_{1,9}$ and $C_{1,2}$ as codes with least adjacency b=0. Neighbors/elapsed_time for vacant codes for $2R$ call are $C_{2,3}$/15, $C_{2,10}$/5 and $C_{2,4}$/5 units respectively. These are designated in group $S(i,b,n)$ as $S(1,0,1)$, $S(1,0,2)$, $S(1,0,3)$. The entries $S(1,0,2)$, $S(1,0,3)$ equally probable and hence any of them is selected.

4 Simulation Results

4.1 Input parameters

- Call arrival process is assumed to be Poisson distributed with average value, λ =1-128 calls/time.
- Service time is assumed to be negative exponential distributed with mean value $1/\mu$ =1 units of time.
- Two categories of rates, quantized and non quantized are assumed. In quantized rates, there are eight classes of users with rates R, $2R$, $4R$ ….$128R$ (R=7.5kbps). For non quantized rates, there are 128 classes of users with rates R, $2R$, $3R$ ….$128R$.
- The capacity of OVSF code tree is $128R$ with root in layer 8 (layer numbering starts from leaves).

4.2 Quantized data rates

Consider that there are $G_k = 2^{k-1}, k = [1,2,..8]$ servers in the k_{th} layer corresponding to G_k number of vacant codes. The total codes (servers) in the system assuming an eight set of classes are given by $G=\{G_1,G_2,G_3,G_4,G_5,G_6,G_7,G_8\}$. The maximum number of servers used to handle new call is equal to the number of rake combiners. Let λ_k , μ_k is the arrival rate, service rate of k^{th} class of users. Traffic load for the k^{th} class of users is given by $\rho_k = \lambda_k / \mu_k$. The code blocking for the k_{th} class is defined by

$$P_{B_k} = \frac{\rho_k^{G_k} / G_k!}{\sum_{n=1}^{G_k} \rho_k^n / n!} \tag{10}$$

The average code blocking for 8 class system is

$$P_B = \sum_{k=1}^{8} \frac{\lambda_k}{\lambda} P_{B_k} \tag{11}$$

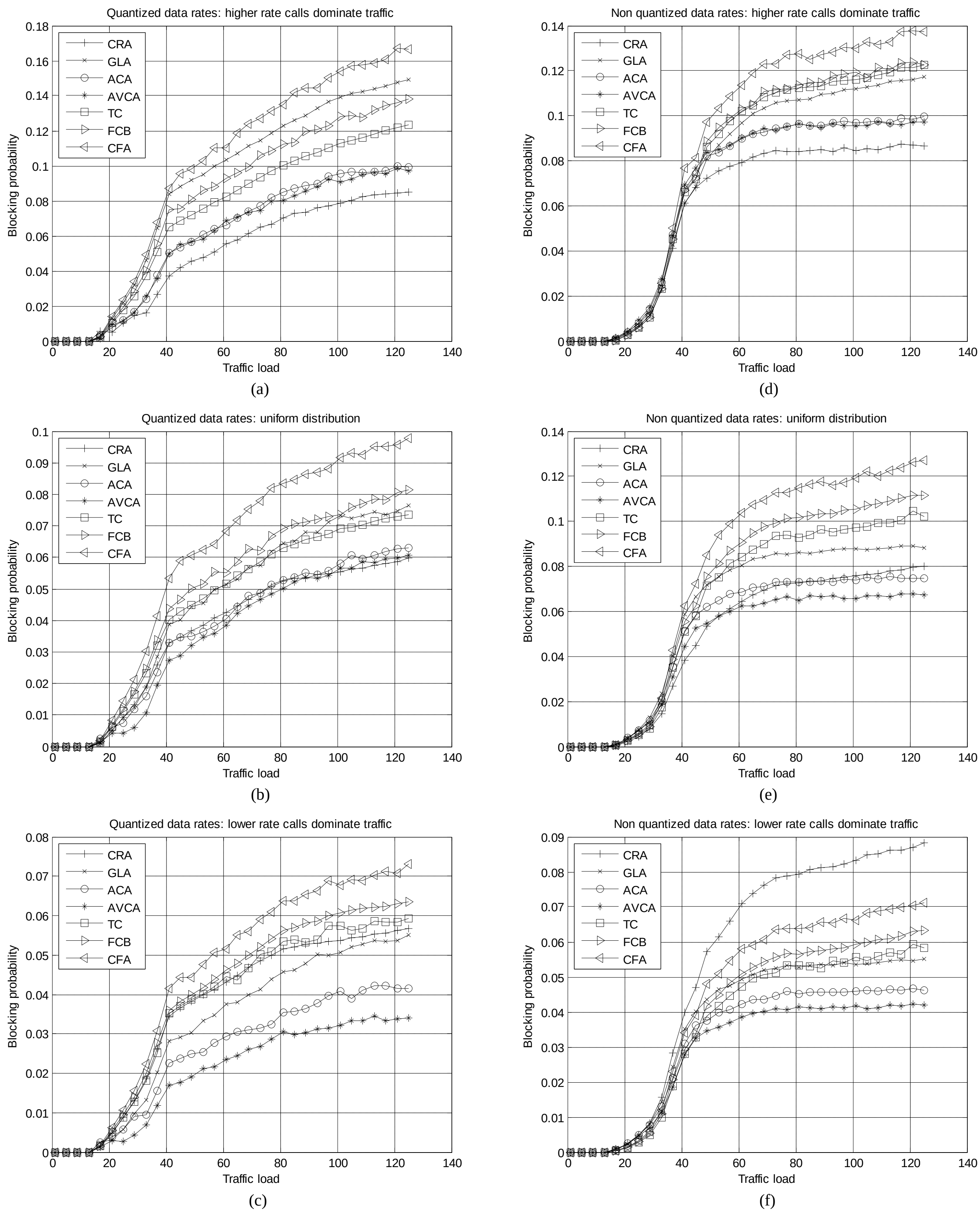

Figure 3 Code blocking vs traffic load for (a) Quantized data rates with high rates dominating (b) Quantized data rates with uniform distribution (c) Quantized data rates with low rates dominating (d) Non quantized data rates with high rates dominating (e) Non quantized data rates with uniform distribution (f) Non quantized data rates with low rates dominating.

We divide the eight classes of calls into two categories namely real time classes (especially for speech signals with rates R, $2R$, $4R$ and $8R$) and non real time calls (with rates $16R$, $32R$, $64R$ and $128R$). The video conferencing comes in higher rate (although it is real time category) class. Let the arrival distribution for the eight classes are given by $[p_1, p_2]$, where p_1 and p_2 is the probability of real time and non real time calls. Three arrival distributions are considered as given below

- [0.75,0.25] for low rate calls dominating the arrival process
- [0.5,0.5] for uniform distribution of eight classes
- [0.25,0.75] for high rate calls dominating the arrival process

The code blocking comparison of the proposed schemes is done with CFA [8], FCB [9] and TC [10] schemes discussed earlier. The nomenclature for the proposed scheme is CRA (code reservation assignment), GLA (group leader assignment), ancestors cost assignment (ACA) and AVCA (adjacent vacant codes assignment). Result in Figure 3(*a*), (*b*) and (*c*) shows that the performance improvement using proposed compact assignment schemes.

4.3 Non quantized data rates

Consider there are 128 classes of users with rates R, $2R$,….$128R$. The arrival rate and service rate is λ_k and μ_k, $k \in [1,128]$. The internal fragmentation adds to the code blocking due to code rate wastage with non quantized rates. The average code blocking is given by

$$P_B = \sum_{k=1}^{128} \frac{\lambda_k}{\lambda} P_{B_k} \tag{12}$$

The arrival distribution for the 128 classes is divided into two sets defined by $[p_1, p_2,]$, where p_1 is the sum of probabilities of rate arrival λ_i, $i \in [1,2,...15]$ assumed to be real time calls and p_2 is the sum of probabilities of rate arrival λ_i, $i \in [16,128]$ assumed to be non real time calls. Three distributions of rates are assumed

- [0.75,0.25] for low rate calls dominating the arrival process
- [0.5,0.5] for uniform distribution of four classes
- [0.25,0.75] for high rate calls dominating the arrival process

Result in Figure 3(*d*), (*e*) and (*f*) shows that the performance improvement using proposed compact assignment schemes.

5. Conclusion

OVSF codes are the limited resources at the downlink of 3G and beyond CDMA based mobile communication systems. The paper discusses compact code assignment schemes for the efficient use of OVSF codes. The code blocking can be reduced by using code assignment scheme according to the arrival distribution of incoming calls. This also increases throughput and code utilization. The complexity of all the code assignment schemes is lower because single rake combiner is required at the BS and at the UE.

References

[1] C. M. Chao, Y. C. Tseng and L. C. Wang, Reducing Internal and External Fragmentation of OVSF Codes in WCDMA Systems with Multiple Codes, *IEEE Transactions on Wireless Communications*, Vol. 4, Jul. 2005, pp. 1516-1526.

[2] A. J. Viterbi, Principles of spread spectrum communications, Addison Wesley, 1995.

[3] F. Adachi, M. Sawahashi, and K. Okawa, Tree-structured generation of orthogonal spreading codes with different lengths for forward link of DS-CDMA mobile radio, *Electronic Letters*, Vol. 33, No. 1, Jan. 1997, pp. 27–28.

[4] E. Dahlman and K. Jamal, Wide-band services in a DS-CDMA based FPLMTS system, *IEEE Vehicular Technology Conference*, Vol.3, 1996, pp. 1656-1660.

[5] B.J. Chang and P.S. Chang, Multicode-based WCDMA for reducing waste rate and reassignments in mobile cellular communications, *Computer Communication*, Vol.29, No.11, , July 2006, pp.1948–1958.

[6] H. W. Ferng, H. L. C. Shiung, D. Y. T. Chen, An OVSF Code Tree Partition Policy for WCDMA Systems Based on the Multi-Code Approach, *IEEE VTC*, Vol.2, 2005, pp. 1212-1216.

[7] F. A. Cruz-Perez, J. L. Vazquez-Avila, A. Seguin-Jimenez, and L. Ortigoza-Guerrero, Call Admission and Code Allocation Strategies for WCDMA Systems With Multirate Traffic, *IEEE*

Journal on Selected Areas on Communications, Vol.24, Jan. 2006, pp. 26-35.

[8] Y.C.Tseng, C.M.Chao, and S.L. Wu, Code placement and replacement strategies for wideband CDMA OVSF code tree management, *IEEE GLOBECOM*, Vol. 1, 2001,pp.562-566.

[9] A. N . Rouskas and D. N. Skoutas, Management of channelization codes at the forward link of WCDMA, *IEEE Commun. Lett.*, Vl. 9, Aug. 2005, pp. 679-681.

[10] S. T. Cheng and M. T. Hsieh, Design and analysis of time-based code allocation schemes in W-CDMA systems, *IEEE Transactions on Mobile Computing*, Vol. 4, No. 6, Nov./Dec. 2005, pp. 604-615.

[11] T. Minn and K. Y. Siu, Dynamic assignment of orthogonal variable spreading factor codes in W-CDMA, *IEEE Journal on Selected Areas in Communications*, Vol. 18, No. 8, Aug. 1998, pp. 1429–1440.

[12] W. T. Chen, H. C. Hsiao, and Y. P. Wu, A novel code assignment scheme for W-CDMA systems, *IEEE Vehicular Technology conference*, Vol. 2, 2001, pp.1182-1186.

[13] J.S. Park, L. Huang, D. C. Lee, and C.C. Jay Kuo, Optimal code assignment and call admission control for OVSF-CDMA systems constrained by blocking probabilities, *IEEE Globecom*, Vol. 5, Nov/Dec. 2004, pp. 3290-3294.

[14] Y. Yang and T. S. P. Yum, Multicode Multirate Compact Assignment of OVSF Codes for QoS Differentiated Terminals, *IEEE Transactions on Vehicular Technology*, Vol. 54, No. 6, Nov. 2005, pp. 2114-2124.

[15] Y. Yang and T.S. P. Yum, Maximally flexible assignment of orthogonal variable spreading factor codes for multirate traffic, *IEEE Transactions on Wireless Communication*, Vol. 3, No. 3, May 2004, pp. 781–792.

[16] D. S. Saini and S. V Bhooshan, OVSF Code Sharing and Reducing the Code Wastage Capacity in WCDMA, Springer Journal of Wireless Personal Communication, Vol. 48, No. 4, Mar., 2009, pp. 521-529.

[17] D. S. Saini and M. Upadhyay, Multiple rake combiners and performance improvement in WCDMA systems, *IEEE Transactions on Vehicular Technology*, Vol. 58, No. 7, Sep. 2009, pp. 3361-3370.

Neeru Sharma was born in Ludhiana, India in November 1979. She received B.E. degree in electronics and telecommunication engineering from College of Engineering, Badnera, Amravati, India in 2001. She received M.E degree in Digital Communication from M.B.M. Engineering College, Jodhpur, Rajasthan, India in 2005. She is with Jaypee University of Information Technology Waknaghat since August 2007. Currently she is Senior lecturer in electronics and communication engineering department. Her research areas include Channelization (OVSF) codes and optimization in WCDMA.

Davinder S Saini was born in Nalagarh, India in January 1976. He received B.E degree in electronics and telecommunication engineering from College of Engineering Osmanabad, India in 1998. He received M.Tech degree in communication systems from Indian Institute of Technology (IIT) Roorkee, India in 2001. He received PhD degree in electronics and communication from Jaypee University of Information Technology Waknaghat, India in 2008.

He is with Jaypee University of Information Technology Waknaghat since June 2002, and he is currently working as an Associate Professor in electronics and communication department. His research areas include Channelization (OVSF) codes and optimization in WCDMA, routing algorithms and security issues in MANETs.