Integrating new calls and performance improvement in OVSF based CDMA Networks

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Abstract: In code division multiple access (CDMA), orthogonal variable spreading factor (OVSF) codes are used to allocate vacant codes when new calls arrive. In this paper, integration is done 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. Voice calls are assigned a busy or vacant code when a call arrives. The rate of data calls can increase or decrease according to the availability of free capacity in code tree or according to type of traffic load. Single code and multi code schemes are proposed which minimize the internal fragmentation of busy codes by utilizing their wastage capacity. In addition, the external fragmentation is also reduced. The vacant code is assigned when busy code wastage capacity is insufficient to handle a call. Simulation results prove dominance of our scheme over other novel schemes.

Keywords: OVSF codes, code blocking, code searches, single code assignment, single code assignment, wastage capacity.

I. INTRODUCTION

THE technological advances and rapid development in handheld wireless terminals have facilitated the rapid growth of wireless communications. Since this tremendous growth of wireless communication requirements is expected under the constraint of limited bandwidth. The bandwidth requirements of current wideband signals are high. One way to achieve high bandwidth is to use specialize modulation as given in [1]. This is particularly useful for multipath propagation in urban mobile radio communication in next generation systems. A novel configuration with match filters is given for efficient and reliable synchronization under multipath environment. In 3G and beyond CDMA systems, the high bandwidth requirement can be tackled using multicarrier communication [2] and OVSF [3] codes are used to handle variable rate which utilizes limited bandwidth efficiently. In general, a higher data rate service can be achieved by assigning a code with smaller spreading factor (SF). The OVSF codes are generated from a class of codes called Hadamard matrices. The Hadamard matrices has many applications along with OVSF based CDMA systems. One such application is given in [4], where construction of optical ZCZ codes is described with the use of Sylvester-type Hadamard matrix. The construction of two categories of codes namely ROM-type and non ROM-type codes is detailed. Basically, the optical ZCZ code is a set of pairs of binary and bi-phase sequences with zero correlation zone. The OVSF codes are assigned to handle calls to preserve the orthogonality between different calls using physical channels. The SF of a code decides the rate of the call that can be supported by an OVSF code. Lower is the position of a code in tree, higher is SF and vice versa. Once a code is assigned, all its ancestors and descendants are blocked. It limits the number of OVSF codes. So, OVSF codes should be allocated efficiently. Further, the fair allocation of codes become difficult as the scattered lower rate codes block high rate codes [5-7]. In OVSF based networks, the treatment of voice calls and data calls is different. The voice calls require single code for full call duration at fixed rate, while the data calls have the flexibility of variable data rate. The treatment of

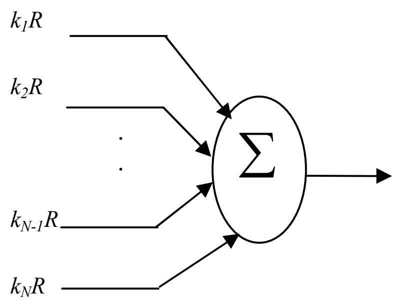

Fig.1 Integration of calls at base station.

real time and on real time calls in most of the systems including GSM, CDMA etc. is different. In [8], the voice calls and real time calls are handled with either complete partitioning (CP) or partial partitioning (PP) methods. The voice traffic, the traffic model used is Erlang Law for both cases CP and PP. On the other hand for data traffic, the models depend upon the scheme used for resource allocation. For CP, the model used is either Erlang law or modified Engset law. For PP, the two models used are bidirectional Markov chain model and modified Engset law. The rate handled by a code in layer $l, 1 \le l \le L$ of OVSF code tree is $2^{l-1}R$, where R is $7.5kbps$. if a non quantized call is assigned to these quantized codes it will lead to internal fragmentation [9]. The external fragmentation occurs due to scattering of busy codes in the code tree which reduces the amount of high rate codes available. The internal and external fragmentation produce code blocking, a situation where the new call will be rejected although the system has enough capacity to handle it.

In literature, a large number of code assignment algorithms are proposed to reduce code blocking. These schemes are divided into two categories namely single code and multi code schemes. In single code schemes, one code is used to handle new call. In multi code schemes, multiple codes are used to handle a call. The multi code mechanism requires the complex transceiver, which may increase the complexity of user equipment (UE) [10]. To reduce the complexity of a UE, single codes assignments are preferred. The single code assignment schemes can be rearrangeable or nonrearrangeable. Most common rearrangeable assignment scheme is dynamic code assignment (DCA) [11] which completely eliminates code blocking by using reassignments. DCA is further improved in terms of spectral efficiency in [12] and complexity of DCA is reduced in [13]. The nonrearrangeable (static) [11] approach uses first fit approach where the optimum code need to be identified at the call arrival. The rearrangeable (dynamic) approach [14] requires current tree status to reassign some of the existing calls to accommodate new call which is based on a tree partitioning method, which requires additional information of traffic arrival rate (distribution of different data rate users). Two priority based rearrangeable code assignment schemes were proposed in [15] and [16], respectively, to handle both the real time calls (video streaming, voice calls etc.) and the non real time traffic (file transfer, e-mail). Real time calls are given higher priority. Specifically, the scheme in [17] makes use of the bursty property of real time traffic and therefore offer higher system utilization. The code assignment scheme suggested in [15] performs code reassignment for real time traffic classes on every call departure instant. At these instants, the right most call in the same layer (of the code tree) is moved to occupy the just released code. As a result, the remaining assignable single code capacity is maximized. Most common (less complex) nonrearrangeable schemes are left code assignment (LCA) [17], crowded first assignment (CFA) [17], fixed set partitioning (FSP) [18], fewer code blocked [19], recursive fewer codes blocked (RFCB) [20], and adaptive code assignment (ADA) [21]. In LCA, a new call is handled by first available vacant code from left. It results in higher code blocking and less call processing delay. CFA assigns new call to most crowded portion of the code tree due to ongoing calls. It reduces code blocking significantly at the cost of higher call processing delay. For locating the most crowded portion, vacant codes parents and children are searched and a code is selected for assignment after comparing other codes which increases call processing delay. FSP divides code tree into sub trees according to traffic arrival rates. This reduces codes searches but results in higher code blocking and leads to wastage of bandwidth for most of the time. LCA and FSP are used for low traffic load. The adaptive code assignment (ADA) [21] makes the code tree division adaptive to arrival distribution. Multi code assignment can support multi rate services using multiple codes with multiple rake combiners. It reduces the code blocking probability because a smaller SF code can be used to replace some higher SF codes to avoid code fragmentation. The multi code schemes proposed in [9], [22], [23] and [24] reduces code blocking using multiple vacant codes scattered in code tree. However, multi codes have many advantages but may cause side effects like increased call processing delay and when multi codes are released, they may split resources, resulting in more fragments which may subsequently result in code blocking of high rate codes. Moreover, the more code fragments we have, the more code reassignments are required which increases complexity.

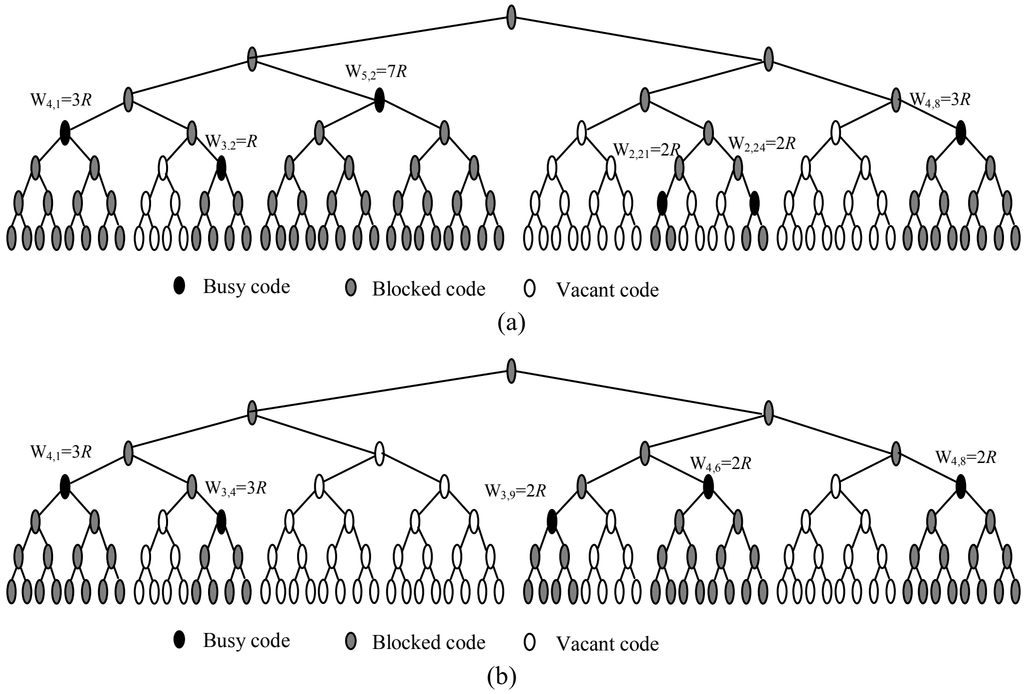

Fig. 2 Illustration for: a) Pure Integration Scheme. b) Voice Call Priority Scheme.

A time based scheme proposed in [25] selects a vacant code on the basis of maximum remaining time. A quality based assignment method in [26] proposes three assignment and reassignment strategies including fixed service data rates and considering a code limited system capacity. The paper in [27] carried out code assignment on the basis of available and guaranteed rate. OVSF codes support call rates that are powers of two *i.e quantized rate* and do not support many intermediate call rates. This reduces some flexibility in the allocation of code resources, and if *non-quantized rates* are assigned OVSF codes it may result in increased internal fragmentation. In this paper, we proposed a single code and a multi code assignment schemes which reduces code blocking by integrating data calls in buffer before assigning them and voice calls are integrated within a code. These schemes reduces internal fragmentation due to ongoing calls by utilizing there wastage capacity. Integration of calls is done as shown in Figure. 1.

The rest of the paper is organised as follows. Section 2 explains proposed integration scheme. The simulation results are given in section 3. Finally, the paper is concluded in section 4.

II. Proposed Integration Calls Scheme

For an OVSF based CDMA tree of L layer. We define a code C_{l,n_l}, where l denotes the layer number and $n_l, 1 \le n_l \le 2^{L-l}$ denotes the code number in layer $l, 1 \le l \le L$ and rate of a code in layer l is $2^{l-1}R$.

A. Pure Integration Call Scheme

a) Call Arrival

If a new call voice or data of rate kR, $1 \le k \le 128$ arrives, search all the busy codes C_{l,n_l} in layer l assigned to ongoing calls with free capacity, where $(l_{\min} \le l \le L)$ & $k \le 2^{l_{\min}}$. The proposed scheme uses wastage capacity of busy codes and handles non quantized rate efficiently. The wastage capacity for a code C_{l,n_l} is defined as $W_{l,n_l} = 2^{l-1}R - \sum_{t=1}^{N_{l,n_l}} k_t R$, where N_{l,n_l} denotes the number of calls code C_{l,n_l} is already handling.

1. Find those busy codes for which $W_{l,n_l} \ge kR$.
2. Find code(s) C_{l,n_l^i}, $i \in [1, j_l]$ denotes the number the busy codes which have minimum wastage capacity after handling new call *i.e* $W_{l,n_l^i}^{new} = W_{l,n_l^i} - kR$ is minimum.
3. If only one such code exists $j_l = 1$ assign new call to it.
4. Else if, for all j_l having same W_{l,n_l}^{new}, find number of voice calls and data calls they are handling. If new call is a voice call assign it to the code handling maximum voice calls. For a new data call, assign it to the code handling maximum data calls.

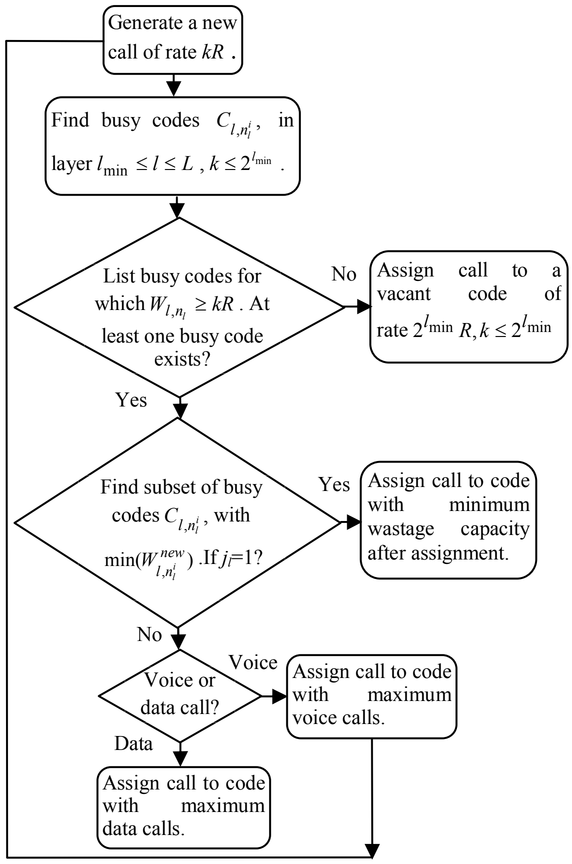

Fig.3 Flow chart for Pure Integration Scheme.

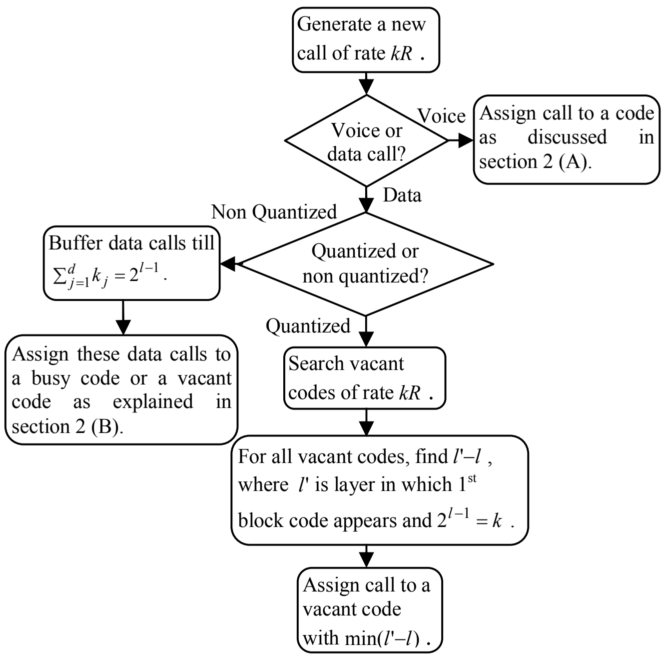

Fig.4 Flow chart of Voice Calls Priority Scheme.

5. Else if, no busy code C_{l,n_l} exists which can handle kR rate call, find a vacant code of rate $2^{n_{\min}} R$, where $2^{n_{\min}} R \geq kR$ and for which $2^{n_{\min}-1} R - kR$ is minimum.
6. Else, no busy or vacant code which can handle call of rate kR is available, then block call.

For illustration consider the status of code tree with wastage capacity of codes shown in Fig.2 (a). When a voice call of rate $3R$ arrives, this call can be directly assigned to vacant codes of rate $4R$ but it will lead to internal fragmentation of amount R which is avoided in our scheme. The wastage capacity of busy codes is assigned to this call to reduce internal fragmentation, codes with wastage capacity $\geq 3R$ are $C_{4,1}$, $C_{5,2}$ & $C_{4,8}$. Codes $C_{4,1}$ & $C_{4,8}$ have minimum wastage capacity. Tie is resolved by checking the type of call they are handling. If $C_{4,1}$ is handling two data calls only and $C_{4,8}$ is handling one data and one voice call. Then new call will assigned to $C_{4,8}$.

b) Call Ends

If a call of rate kR ends of a code C_{l,n_l^i} three scenarios are possible:

i. Code handling only Voice calls

Calculate wastage capacity after a call ends $W^{end}_{l,n_l^i} = W_{l,n_l^i} + kR$ of code C_{l,n_l^i} and store the information how much more rate this code C_{l,n_l^i} can handle which is equal to W^{end}_{l,n_l^i}. Wait for voice call arrival and assign this code to voice call. However, if no other code C_{l,n_l^i} *i.e* $j_l = 1$ with free capacity to handle data call exists, then this capacity can be assigned to data calls.

ii. Code handling only Data calls

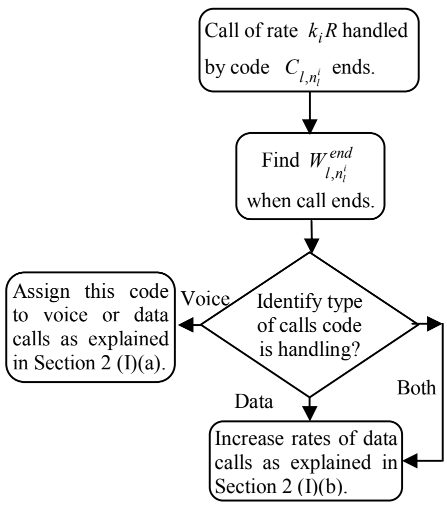

Fig. 5 Flow chart of Integration Scheme when a call ends.

If all the remaining calls of code C_{l,n_l^i} are data calls, then increase rate of remaining data call(s) which will decrease their remaining time. Let the code is handling x calls, find the call with maximum remaining time or maximum data rate. If call with maximum remaining time is assigned a rate $k_d R$ and a call of rate k ends. It will increase data rate of $k_d R$ to $(k_d + k)R$ and remaining time will decrease by t'_d α $(1/k_d R)$- $(1/(k_d + kR))$. If a call arrives and no busy code available to handle it and reducing the rate of data calls to their initial value can handle this call, then data calls are assigned their initial or reduced rate. The reduced rate is the rate subtracted from excess data rate assigned to call with maximum remaining time after handling new call.

iii. Code handling both voice and data calls

If code is handling both voice and data calls, increase rate of data calls as discussed above.

For illustration consider Figure 2 (a). The present status of code tree after assigning $3R$ rate to $C_{4,8}$ will be $W_{4,8}$=0. $C_{4,1}$ & $C_{5,2}$ wastage capacity is utilized by the data calls assigned to these codes. Let $C_{4,1}$ is handling a call of rate $4R$ and R & $C_{5,2}$ is handling a call of rate $5R$ and $4R$. If another call of $3R$ arrives, then $C_{4,1}$ will be the code with minimum wastage capacity, as explained above. Let code $C_{5,2}$ is handling calls of rate $4R$, $4R$, R and one of the $4R$ rate call is data call. Wastage capacity $W_{5,2}$ =$7R$ can be used by data call. $4R$ rate data call is then handled by $11R$ rate. If at the start of $4R$ rate call its remaining time is $t_{4R}\ \alpha\ (1/4R)$ and time spent before getting $7R$ rate capacity is assigned to it is t'_{4R}, then its remaining time is $t_{4R} - t'_{4R}$. Now, data will be transferred at a faster rate $11R$. Rate of $4R$ is reduced again to its original or lesser rate when another call of rate $kR, 1 \leq k \leq 7$ arrives, if elapsed time of data call handled by $11R$ rate is t'_{11R}, then remaining time of call will be $t_{4R} - t'_{4R} - t'_{11R}$. Let data transferred during t'_{11R} is d, then $t'_{11R} = d/11R$. If same data is to be transferred using $4R$ rate, then time taken will be $t''_{4R} = d/4R$ which is greater then t'_{11R}. Assigning wastage capacity (unused capacity) is assigned to other data calls it reduces time taken by that call to transfer data and reduces code blocking.

B. Voice calls Priority Scheme

When a voice call arrives, it is handled without delay as explained above in pure integration scheme. The data calls which are not delay sensitive can be stored in buffer. For a new data call of rate kR and if code tree is not handling any data call, then

- If $k = 2^{l-1}, 1 \leq l \leq 8$, list all vacant code of rate kR and assign call to vacant code which will lead to zero or minimum blocking of higher rate codes. This new code will be of layer l and if first block code above it appears in layer l', than assign new call to vacant code with $\min(l'-l)$.

- If $k \neq 2^{l-1}, 1 \leq l \leq L$,
  Then queue data calls in buffer and add all data calls till $\sum_{j=1}^{d} k_j = 2^{l-1}, 1 \leq l \leq L$, d is the number of data calls added. Assign all data calls in queue to a vacant code C_{l,n_l} which will result in minimum blocking of higher layer code *i.e* $\min(l'-l)$ or to a busy code which can handle all these data calls.
- Else assign sum of data calls after waiting for a particular time in buffer to a vacant code of lower rate which will increase data transfer time. However, it will reduce code blocking significantly for both voice and data calls.

For illustration consider the status of code tree in Fig.2

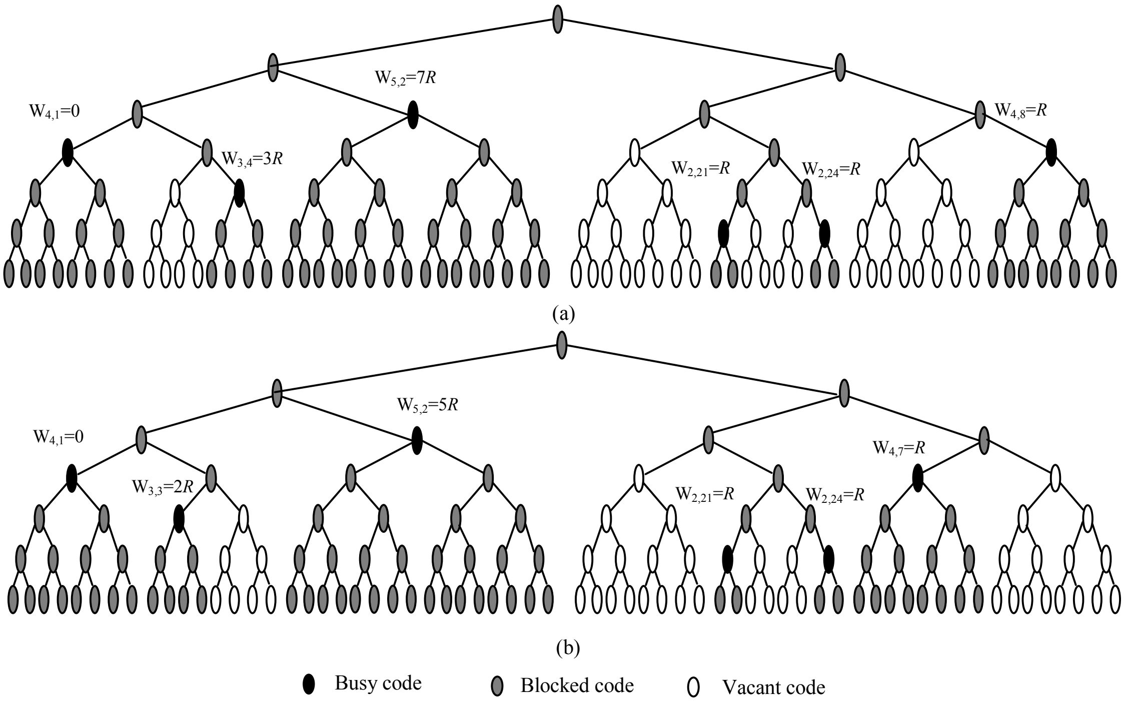

Fig.6 Multi Code Integration Scheme: (a) Using wastage capacity, (b) Using wastage capacity then using free capacity.

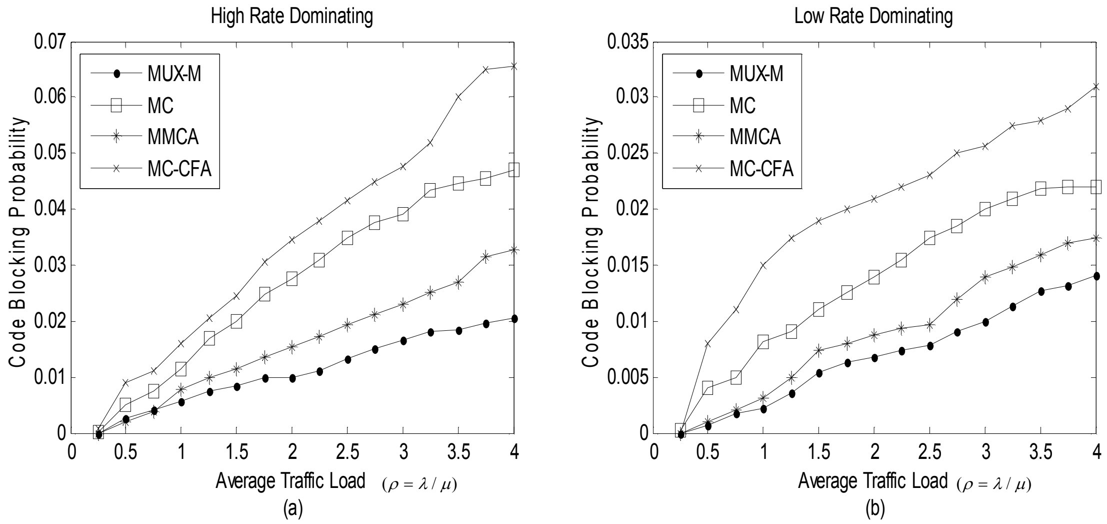

Fig. 8 Comparison of Code blocking probability in multi code Schemes for distribution: (a) High Rate Dominating: 2 rakes, (b) Low Rate Dominating: 3 rakes.

(b). When a data call of rate 6R arrives, as $6 \neq 2^{l-1}$, queue it in buffer and wait for data calls till sum of all calls is equal to a quantized value. If another data call of rate 2R arrives, sum of both can be handled by $C_{4,7}$.

C. Multi code Integration Scheme

If a call of rate kR cannot be handled using a single code, then multi codes can be used to handle the call utilizing all or required rakes. The multi code integration of voice and data calls uses vacant codes capacity after utilizing total wastage capacity.

a) Find total free capacity T_{l,n_l} *i.e* sum of wastage capacity $\sum_{l=1}^{L} W_{l,n_l}$ of the busy codes or vacant codes free capacity $\sum_{l=1}^{L} V_{l,n_l}$, $T_{l,n_l} = \sum_{l=1}^{L} W_{l,n_l} + \sum_{l=1}^{L} V_{l,n_l}$. Arrange busy codes C_{l,n_l} in decreasing order of their wastage capacity and vacant codes C_{l,n_l} in increasing order of their free capacity.

b) If $\sum_{l=1}^{L} W_{l,n_l} \geq kR$,
let available busy codes are x and there wastage capacity $\sum_{i=1}^{x} W_{l,n_l}(i) = \sum_{l=1}^{L} W_{l,n_l}$.
$Sum(W_{l,n_l}) = 0$, i=0;
While ($Sum(W_{l,n_l}) = kR \parallel i=x$)
$Sum(W_{l,n_l}) = Sum(W_{l,n_l}) + W_{l,n_l}(i)$;
i=i+1;
End;
Assign call to i codes required using minimum number of rakes or maximum rakes to handle the call. The algorithm picks higher rate busy code(s) with wastage capacity and vacant code of required capacity to handle new call in case of minimum rakes as in Figure. 6(b).

c) Else if
let available busy codes are x and y and there free capacity is $\sum_{i=1}^{x} W_{l,n_l}(i)$ and $\sum_{i=1}^{y} V_{l,n_l}(j)$.
$Sum(W_{l,n_l}) = 0$, i=0;
While ($Sum(W_{l,n_l}) = kR \parallel i=x$)
$Sum(W_{l,n_l}) = Sum(W_{l,n_l}) + W_{l,n_l}(i)$;
i=i+1;
End
if i=x;
j=0;
$Sum(W_{l,n_l}) = Sum(W_{l,n_l}) + V_{l,n_l}(j)$;
j=j+1;
End;

d) Else
Block call.

e) End;

For illustration consider the status of code tree in Figure. 6(a). When a data call of rate 10R arrives, no single code is available which can handle this call. The total wastage capacity is 13R and free capacity is 20R. The vacant code available in code tree will be used when busy code capacity is less then call requested. The algorithm picks busy code $C_{5,2}$ whose wastage capacity is 7R and another busy code $C_{3,4}$ with wastage capacity 3R utilizing two rakes. It uses wastage

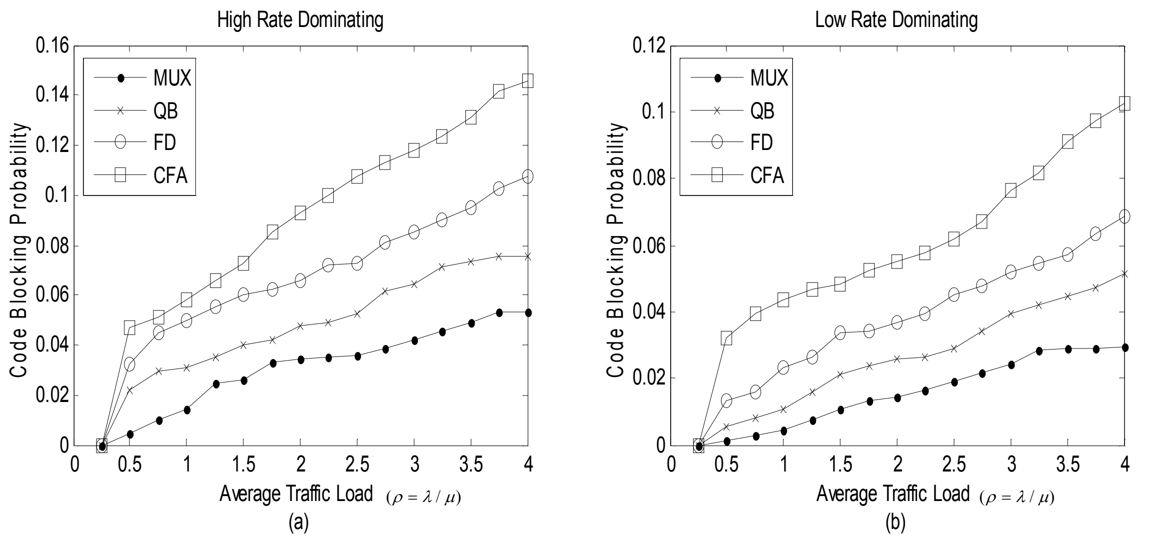

Fig. 7 Comparison of Code blocking probability in single code Schemes for distribution:
(a) High Rate Dominating: 2 level sharing, (b) Low Rate Dominating: 3 level sharing.

capacity of busy codes. For illustration of wastage capacity and free capacity consider the status of code tree in Figure. 6 (b), when a new call of 14*R* arrives two cases are possible.

i) Minimum rakes: If only three rakes available pick two codes with maximum wastage and one vacant code for remaining required capacity or pick one code with maximum wastage and two vacant codes for remaining required capacity. For example of Figure. 6(b) picks codes $C_{5,2}$, $C_{3,3}$ with wastage capacity 5*R*,2*R* respectively and vacant code $C_{4,5}$ with free capacity to handle this call. This will work on number of rakes available and uses maximum possible wastage capacity.

ii) Maximum rakes: Pick all busy codes with wastage capacity $C_{5,2}$, $C_{3,3}$, $C_{3,21}$, $C_{2,24}$, $C_{4,7}$ whose total free capacity is 10*R* and vacant codes $C_{2,22}$, $C_{2,23}$ whose free capacity is 4*R*. This system utilizes total wastage capacity at the cost of more complexity requiring seven rakes to handle same call.

III. SIMULATION PARAMETERS AND RESULTS

A. Traffic Conditions

The codes blocking probability performance of the integration single and multi code schemes are compared with existing schemes in literature. For simulation, following classes of users are considered with rates *R*, 2*R*, .. 15*R* respectively.

- The arrival rate λ is assumed to be Poisson distributed with mean value varying from 0-4 calls per unit of time.
- Call duration is exponentially distributed with mean value of 3 units of time.
- The maximum capacity of the tree is 128*R* (*R* is 7.5*kbps*). Simulation is done for 5000 users and result is average of ten simulations.

B. Results

Define $[p_1,p_2,..p_{16}]$ as probability distribution matrix where p_i, $i \in [1,16]$, is the capacity portion used by the i^{th} class users. The total codes (servers) in the system for sixteen set of classes are the given by set $G = \{G_0, G_1, .., G_{15}\} = \{R, 2R ...., 15R\}$ Two distribution scenarios are analyzed and are given by

- High rate calls dominating
- Low rate calls dominating

The blocking probability is caused by two reasons: insufficient free capacity in code tree, which causes the so-called capacity blocking and code fragmentation which results in the code blocking probability. Consequently, the blocking probability is composed of the capacity blocking probability and the code blocking probability. The code blocking for a 16 class system is given by

$$P_B = \sum_{i=1}^{16} \frac{\lambda_k P_{B_i}}{\lambda} \qquad (1)$$

where P_{B_i} is the code blocking of i^{th} class and is given by

$$P_B = \frac{\rho_k^{G_k} / G_k!}{\sum_{n=1}^{G_k} \rho_k^n / n!} \qquad (2)$$

where $\rho_k = \lambda_k / \mu_k$ is the traffic load for k^{th} class.

To decrease the code tree fragments resulting from allocating and releasing codes, allocation of wastage capacity of ongoing calls parents is an imperative procedure to enhance system performance. For single code assignment of integration scheme two and three calls can be assigned to a code *i.e* two or three level sharing of a code in Figure 7(a) and Figure 7(b) respectively. The two level sharing is used for high rate dominating scenario as number of calls requested will be less as compare to low rate dominating scenario. In Figure 7, we compare the proposed schemes with quality based (QB) assignment scheme in [26], fast dynamic scheme in [12] and CFA in [17]. The results shows that for high rates dominating scenario and low rates distribution, the proposed design provides significantly less code blocking as compare to rest of the three schemes and high rates dominating scenario provides less external fragmentation compared to low rates dominating scenario.

The use of multi code reduces the code blocking due to reduction in internal and external fragmentation at the cost of complexity. The code tree is better utilized. In general, by the addition of each rake, the code blocking is reduced by half. Also, the multi code design is more efficient in handling non-quantized data rates. For multi code assignment of integration scheme two and three rakes are used for high rate dominating scenario Figure 8(a) and low rate dominating scenario Figure 8(b) respectively. We evaluated the performance of the proposed integration multi code scheme against the multi code assignment schemes presented in [9], MMCA in [22] and multi code CFA [17] (MC-CFA). Integration multi code assignment scheme provides minimum code blocking with less complexity as it uses wastage capacity of busy codes first and then utilizes free capacity of vacant codes which leads to new code blocking when all wastage capacity is utilized and also uses minimum rakes to handle a call.

IV. CONCLUSION

Capacity of OVSF based WCDMA a precious resource. The wastage capacity increases more for non quantized rates. In this paper, an integration scheme is proposed which reduces wastage capacity due to non quantized and quantized rates. Two single and one multi code assignment schemes are proposed which handle voice call on priority and multiplex data calls in buffer till a vacant code is available. Work can be done to provide fairness to incoming call rates.

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