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Call Departure Reassignment and Performance Enhancement of OVSF codes in Downlink of CDMA Based Networks

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Abstract

The use of orthogonal variable spreading factor (OVSF) codes give an additional advantage of addressing variable rate requirement of CDMA networks. However, these codes suffer from code blocking problem which further increases due to random nature of call arrival and departure. When a call departs the vacant capacity of the call creates fragmentation in the sub tree where it belongs. The proposed assignment schemes in this paper, in order to reduce fragmentation assigns fragmented vacant capacity of this sub tree to other sub tree(s) and vice versa using reassignment. The proposed schemes guarantees reduced blocking of future high rate calls. It also leads to good system throughput and fairness. Through simulations, it has been demonstrated that the proposed scheme(s) not only adequately reduces code blocking probability but also requires significantly lesser number of code searches as reassignment process is activated in offline mode and online mode is used to locate a vacant code for assignment, which makes it suitable for the real time calls.

Keywords: OVSF, code blocking, code searches, single code assignment, call establishment delay.

INTRODUCTION

The next generation wireless communication systems have to support high data rate and variable data rate in addition to traditional voice calls. This leads to requirement of efficient utilization of radio resource to meet variable traffic demands. The wideband code division multiple access (W-CDMA) technology has emerged as a solution to address these requirements and as a candidate for radio access in Universal Mobile Telecommunication Systems (UMTS) [1-4]. In W-CDMA systems, orthogonal variable spreading factor (OVSF) codes are used to spread and channelize codes [5-6]. The OVSF codes can be represented by a binary tree [7]. The use of OVSF codes allows the spreading factors to be changed for variable bit rate. An assigned code blocks all its parents and children codes in all the layers in OVSF code tree, in order to preserve orthogonality. This leads to code blocking problem *i.e* a new call arriving in the system will be blocked even though the system has enough capacity to support it. A new call arriving in the system should be allocated to maintain flexibility and efficiency for future higher rate requests. However, after a period of time, some codes are released and the code tree may be too fragmental for high bit rate requests to be assigned which enhances code blocking. Therefore, efficient management of these codes is required at the downlink. The condition becomes more severe when rate requirement of calls is diverse which results in more fragmentation of tree capacity. The code blocking is explained using present status of Fig. 1 (a), where the maximum capacity of the code tree is $64R$ (R=7.5 *kbps*). The used capacity of code tree is $26R$ and remaining vacant capacity of the code tree is $(64\text{-}26)R = 38R$. If a new call with rate $16R$ arrives, the call will be blocked due to non availability of a single code of rate $16R$. This occurs due to external fragmentation [8-9] and produces code blocking. The other reason of code blocking is internal fragmentation [8-9]. If there is not enough capacity to support the request, the call will be blocked. Such type of blocking is called the capacity blocking. The call is blocked either due to capacity blocking (not enough capacity) or code blocking (vacant capacity fragmented). The call blocking probability is the sum of the capacity blocking probability and the code blocking probability.

In literature, several code allocation and reassignment schemes have been proposed [8-13]. The main goal of these schemes is to make the assigned code tree as compact as possible and allow free codes to be aggregated together to accommodate incoming high data-rate calls. The schemes in [8,9] uses both code placement and replacement scheme to handle new calls in order to reduce internal and external fragmentation. A dynamic code allocation (DCA) scheme is proposed in [10] for code reassignment. The DCA scheme is based on code pattern search and has the minimum reassignment cost. All the above work is in the category of space-based schemes in which code allocation is based on the space factor of the code tree. A scheme which supports non-real time calls is proposed in [14] and it also constructs the code tree according to the number of users in the system. It would be useful to maximize the transmission rate in the homogeneous communication situation as suggested by simulation results. The scattering is reduced by handling non quantized calls using multi codes in [15]. The quality based

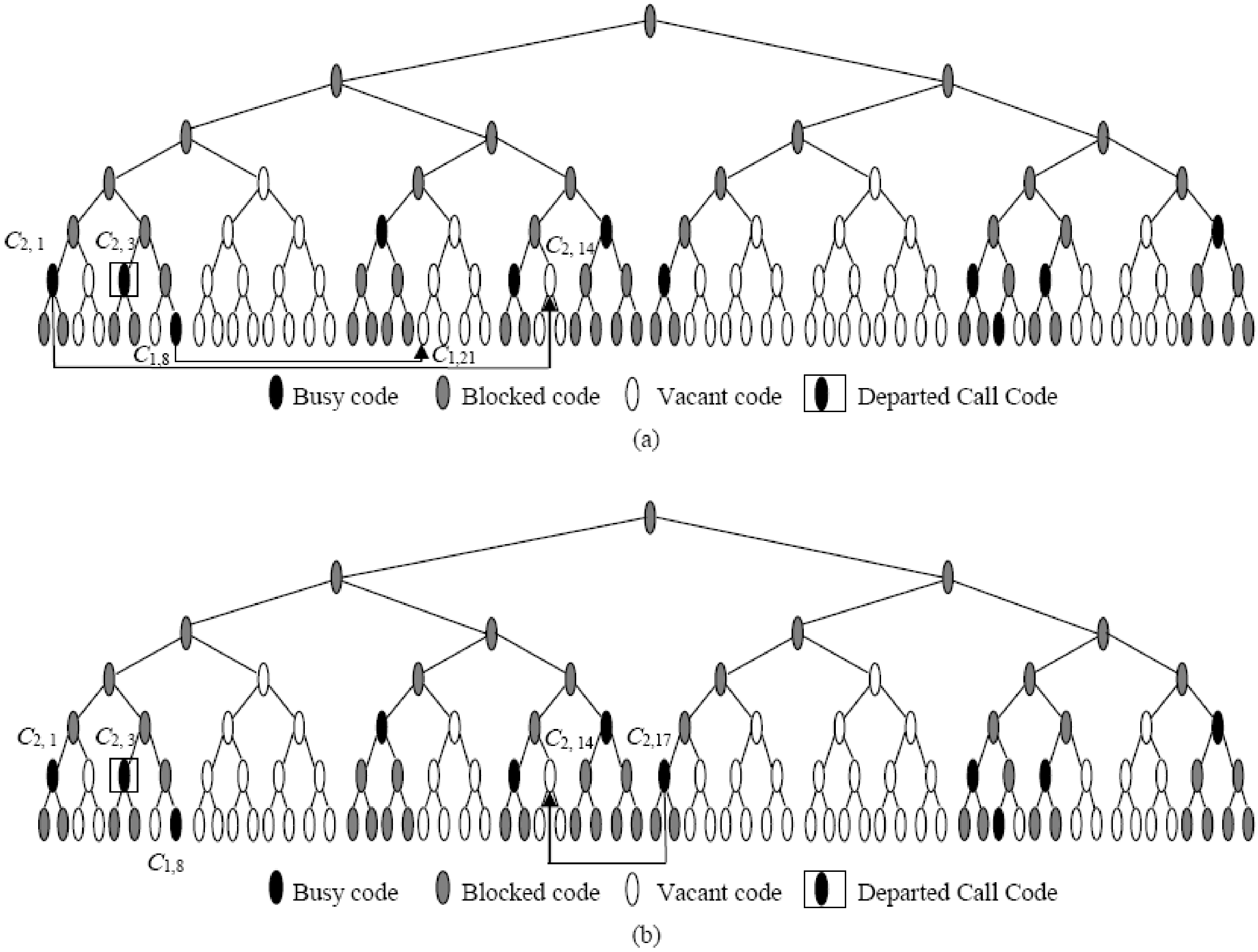


Figure 1: Reassignment under same sub tree: (a) RSR approach (b) RSM approach.

assignment and reassignment strategies in [16] handle variable service data rates for an interference limited system which minimizes number of code allocation. A same rate fraction [17] scheme is proposed which assigns new call to the portion crowded by same rate calls. A top down scheme [18] locates an optimum code by searching code tree from root code and which leads to lesser call establishment delay. If delay is considered as a parameter to differentiate these calls then they are broadly classified as real time calls (which cannot tolerate delay) and non-real time calls (which can tolerate delay). The fixed capacity and variable member grouping assignment scheme [19] proposed in this paper divide the code tree capacity into groups, each group capacity is further divided among multiple rate requests such that each group has at least one member (code) of rate request arriving in the system. This leads to fairness among all types of call requests, reduction in code blocking and reduction in call establishment delay. In fixed set partitioning (FSP) [20], the code tree is divided into a number of sub trees according to the number of input traffic classes and their distribution. This scheme requires minimum number of code searches before assignment but suffers from high code blocking problem.

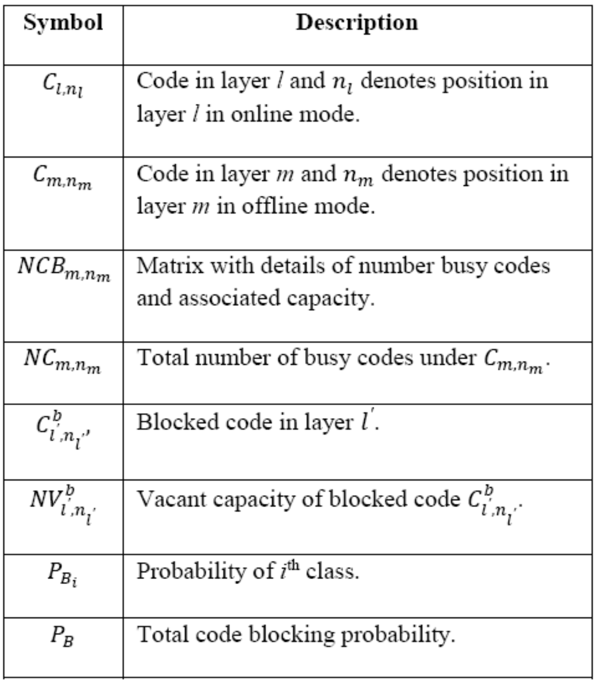
The objective of code assignment scheme is to provide the best code utilization and least code blocking probability. The next generation traffic contains real time calls which cannot tolerate delay upon arrival; the assignment scheme should address this parameter too. The reassignment schemes in literature starts reassignment process upon the arrival of a new request for a code, the occupied codes may be rearranged in the code tree to aggregate the vacant capacity for accepting the new request, the search for which leads to a considerable call establishment delay. The reassignment scheme in this paper starts reassignment process when a call departs and uses the offline time for reassignment which leads to better utilization of both busy and vacant codes. It also requires lesser call establishment delay when a call arrives for assignment due to lesser fragmentation of vacant capacity.

The rest of the paper is organized as follows. In Section 2, the proposed departure reassignment scheme is described. In Section 3, the simulation results are presented and compared with other novel schemes in literature to illustrate the system performance. The conclusion is given in Section 4.

REASSIGNMENT SCHEME

Consider an OVSF based CDMA network using a code tree of L layer. A code in layer l is denoted as $C_{l,n_l}, 1 \leq n_l \leq 2^{L-l}$,$1 \leq l \leq L$ and its mth level parent is $C_{l+m,n_{l+m}}$, where $n_{l+m} = \left\lfloor \frac{n_l}{2^m} \right\rfloor$ and mth level children will be $C_{l-m,n_{l-m}}$, where $n_{l-m} = n_l \times 2^m$ or $n_{l-m} = n_l \times 2^m + 1$. All the codes in code tree have quantized rates of the form $2^{l-1}R$. The notations and abbreviations used in this paper are given in Table 1.

Table 1. *Nomenclature*



Symbol	Description
C_{l,n_l}	Code in layer l and n_l denotes position in layer l in online mode.
C_{m,n_m}	Code in layer m and n_m denotes position in layer m in offline mode.
NCB_{m,n_m}	Matrix with details of number busy codes and associated capacity.
NC_{m,n_m}	Total number of busy codes under C_{m,n_m}.
$C^{b}_{l',n_{l'}}$,	Blocked code in layer l'.
$NV^{b}_{l',n_{l'}}$	Vacant capacity of blocked code $C^{b}_{l',n_{l'}}$.
P_{B_i}	Probability of ith class.
P_B	Total code blocking probability.

The arrival traffic is considered for online mode and departing traffic is considered for offline mode. The notation C_{l,n_l} is used for codes in online mode search and for offline mode search C_{d,n_d} is used, where $1 \leq d \leq L$. The assignment scheme in online mode searches a vacant code from left to right in code tree and assigns new call to first available vacant code otherwise block it. The reassignment of call(s) is done in offline mode and is active when a call departs.

Let a call of rate $2^{d-1}R$ (R =7.5 *kbps*) ends, leaving behind a code C_{d,n_d}vacant. This vacancy will create fragmentation in the code tree. In offline mode, this vacancy can be used to reduce future code blocking of higher layer code requests. The proposed reassignment works in offline mode to reduce code blocking probability of the system and searches number of busy code(s) under a sub tree when a call departs. The algorithm to find busy codes under a sub tree from where a call departs and work is as follows.

1. Check the status of its parent in m layers, where $(d+1) \leq m \leq L$, till a block code appears.
2. Let a block code $C_{d+m,n_{d+m}}$, where $n_{d+m} = \left\lfloor \frac{n_d}{2^m} \right\rfloor$ appears in layer i above it, whose one children is vacant and another is busy or blocked. The children codes of $C_{d+m,n_{d+m}}$ are $C_{d',n_{d'}}$ where $d' = (d+m-1)$ and $n_{d'} = n_d \times 2$ or $(n_d \times 2) + 1$.
3. Go to children code of $C_{d+m,n_{d+m}}$ *i.e* $C_{d',n_{d'}}$which is not vacant. There are two possibilities of it, either *blocked* or *busy*.
   a) **Blocked:** Check status of all children codes of $C_{d',n_{d'}}$in all layers and form a matrix which stores the information of number of busy codes of a particular layer and capacity.

   The matrix will be $NCB_{d+m,n_{d+m}} = \begin{bmatrix} Number\ of\ busy\ codes \\ Capacity\ of\ the\ code \end{bmatrix} = \begin{bmatrix} k_1 & k_2 .. & k_h \\ R & 2R .. & 2^{h-1}R \end{bmatrix}$, where k_1,k_2, and k_h, denotes number of busy codes of rate R, $2R$…and $2^{h-1}R$ respectively and $h \leq (d+m-1)$. The total number of busy codes under sub-tree $C_{d+m,n_{d+m}}$ will then be $NC_{d+m,n_{d+m}} = \sum_{x=1}^{d+m-1} k_x$ and total busy capacity is $NB_{d+m,n_{d+m}} = \sum_{x=1}^{(d+m-1)} k_x \times 2^{x-1}R$.

   b) **Busy:** A code of capacity $2^{d'-1}R$ is busy under sub-tree of $C_{d+m,n_{d+m}}$*i.e.* $NCB_{d+m,n_{d+m}} = \begin{bmatrix} 0 & 0 .. & 1 \\ R & 2R .. & 2^{d'-1}R \end{bmatrix}$,

   $NC_{d+m,n_{d+m}} = 1$ and $NB_{d+m,n_{d+m}} = 2^{d'-1}R$.
4. The total vacant capacity under sub-tree of $C_{d+m,n_{d+m}}$ is $NV_{d+m,n_{d+m}} = 2^{d+m-1}R - NB_{d+m,n_{d+m}}$.

Let $d+m = l'$, the ongoing calls under $C_{l',n_{l'_d}}$ can be reassigned to other codes$C_{l',n_{l'}}$, where ($1 \leq n_{l'} \leq 2^{L-l'}$ & $l' \neq d+m$) are in same layer and vice versa. The reassignment process is iterative and can be carried out in two ways, which is further divided into two.

Reassigned calls should be under the same sub tree

Reassignment of calls from a sub tree from where a call departs.

Initiate reassignment of call from where call departs to another single sub tree (RSR) approach. Arrange all the blocked codes of l' layer in ascending order of their vacant capacity. The vacant capacity of these blocked codes is denoted by $NV^{b}_{l',n_{l'}}$ where b signifies a blocked code, these codes should satisfy$NV^{b}_{l',n_{l'}} \geq NB_{l'n_{l'_d}} \mid n_{l'} \neq n_{l'_d}$. Select the blocked code $C^{b}_{l',n_{l'}}$which satisfies both conditions *i.e* $\min(NV^{b}_{l',n_{l'}})$ and with k_h number of vacant codes of rate

$2^{h-1}R$, where h denotes its layer number $1 \le h \le (l' - 1)$. For example consider a call of rate $2R$ assigned to $C_{2,3}$ leaving behind busy codes of rates $2R$ and R assigned to $C_{2,1}$ and $C_{1,8}$ respectively blocking a code $C_{4,1}$ of rate $16R$. However, the reassignment is done from sub tree where call departs, therefore code $C_{2,17}$ is reassigned to $C_{2,14}$ shown with arrows in as shown in Fig. 1(a) which leads to a vacant code $C_{5,1}$ of rate equal to $16R$.

Reassignment of calls from minimum busy sub tree.

Initiate, reassignment from minimum busy sub tree to another single sub tree (RSM) approach when a call departs from anywhere in code tree. Arrange all the blocked codes of l' layer in ascending order of their vacant capacity. The vacant capacity of these blocked codes is denoted by $NV^b_{l',n_{l'}}$ where b signifies a blocked code. Pick the blocked code $C^b_{l',n_{l'}}$ with $\min(NV^b_{l',n_{l'}})$ and assign all calls under it to the another code in same layer which satisfies both conditions i.e $\max(NV^b_{l',n_{l'}})$ and k_h number of vacant codes of rate $2^{h-1}R$, where h denotes its layer number $1 \le h \le (l' - 1)$. For example consider a call of rate $2R$ assigned to $C_{2,3}$ leaving behind busy codes of rates $2R$ and R assigned to $C_{2,1}$ and $C_{1,8}$ respectively blocking a code $C_{4,1}$ of rate $16R$. However, the reassignment is done from minimum busy sub tree, therefore code $C_{2,17}$ is reassigned to $C_{2,14}$ which leads to a vacant code $C_{5,3}$ of rate equal to $16R$ as shown in Fig. 1(b) with minimum reassignment *i.e* 1.

Reassigned calls are scattered

Reassignment of calls from a sub tree from where a call departs to remaining code tree.

Initiate, reassignment of call(s) from where a call departs to anywhere in code tree (RSCR) approach. Let k_h denote number of calls of rate $2^{h-1}R$, where h denotes its layer number $1 \le h \le (l' - 1)$ under the sub tree of $C_{l',n_{l'_d}}$ and let total number of calls under it are $t_c = \sum_{h=1}^{l'-1} k_h$. Arrange all the blocked codes of l' layer in ascending order of their vacant capacity. The vacant capacity of these blocked codes is denoted by $NV^b_{l',n_{l'}} | \, n_{l'} \ne n_{l'_d}$ where b signifies a blocked code. The algorithm reassigns all calls under $C_{l',n_{l'_d}}$ to other vacant codes under $C^b_{l',n_{l'}} | \, n_{l'} \ne n_{l'_d}$ in same layer starting from code with $\min(NV^b_{l',n_{l'}})$. The algorithm works as follows.

While ($k_h \ne 0$), where $1 \le h \le (l' - 1)$.

Reassign call(s) of rate $2^{h-1}R$ under $C_{l',n_{l'_d}}$ to vacant codes of same rate under code $C^b_{l',n_{l'}}$, where $1 \le b \le m$ and m denotes total number of busy codes in layer l' whose vacant capacity(vacant codes) can be used to handle reassigned call(s) under code $C_{l',n_{l'_d}}$. For each code $C^b_{l',n_{l'}}$, find total vacant capacity used $k_h \times 2^{h-1}R$ and update $NV^b_{l',n_{l'}} = NV^b_{l',n_{l'}} - k_h \times 2^{h-1}R$ and $NB^b_{l',n_{l'}} = NB^b_{l',n_{l'}} + k_h \times 2^{h-1}R$.

$k_h = k_h - 1$;
End;

This reassignment of calls in scattered form will lead to better code utilization as reassigned calls will use vacant capacity of already blocked codes and will not lead to new code blocking of higher rate. For example, consider a call of rate $2R$ assigned to $C_{2,3}$ leaving behind busy codes of rates $2R$ and R assigned to $C_{2,1}$ and $C_{1,8}$ respectively blocking a code $C_{4,1}$ of rate $16R$. For reassignment, fragmented code(s) in complete tree are utilised which leads to minimum new blocking, therefore calls assigned to codes $C_{2,1}$ and $C_{1,8}$ will be reassigned to $C_{2,14}$ and $C_{1,32}$ respectively which leads to a vacant code of rate equal to $16R$ and zero new blocking of codes shown in Fig. 2 and also full capacity utilization of codes $C_{3,13}$ ($C_{2,26}$) and $C_{3,7}$.

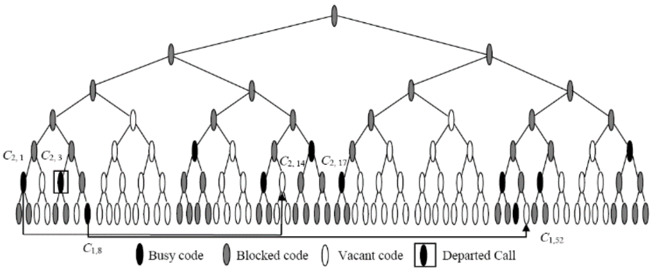


Figure 2: Reassigned calls are scattered: RSCR approach.

Reassignment of calls from minimum busy sub tree of code tree when a call departs.

Initiate, reassignment under the same sub tree from minimum busy sub tree (RSCM) approach. The process of selecting a sub tree where calls will be reassigned will be same as in Section 2.2.1.

SIMULATIONS AND RESULTS

In the following, simulation is used to study the performance of proposed schemes. The simulation parameters are given in Table 2. Two distribution scenarios are considered, the arrival of a call of particular rate is on the basis of its capacity. For example, a call of rate $8R$ will be requested after 8 calls of rate R, 4 calls of $2R$ and 2 calls of rate $4R$. For simulations, maximum rate requested is $8R$ and rate requests are $8R$, $4R$, $2R$ and R.

- [25,25,25,25,25]: Capacity of each rate is uniform.
- [40,30,10,10,10]: Capacity of low rate calls dominating.

Table 2. *Simulation Parameters*

Parameter	***Value/Range***
User Classes	R, $2R$, $4R$, $8R$, $16R$
Arrival rate (λ) is Poisson Distributed	Mean value varying from 0-4 calls/minute
Call duration ($1/\mu_i$) is Exponentially Distributed	Mean value of 3 minutes.
Total Capacity of Code tree	$128R$(R=7.5 *kbps*)
Number of users	10000
Results average	10
Arrival rate and service rate for i^{th} class	λ_i and μ_i , $i \in [1,5]$
Average Traffic Load	$\rho = \sum_{i=1}^{5} \lambda_i / \mu_i$
Probability Distribution Matrix	$[p_1,p_2,p_3,p_4,p_5]=[p_i]$, $i \in [1,5]$

For Poisson's distributed arrival rate λ the average code blocking of a 5 class system is defined as

$$P_B = \sum_{i=1}^{5} (\lambda_i P_{B_i} / \lambda) \qquad (1)$$

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

$$P_{B_i} = \frac{\rho_i^{G_i} / G_i!}{\sum_{n=1}^{G_i} \rho_i^n / n!} \qquad (2)$$

Where $G = [G_1, G_2, G_3, G_4, G_5] = [R, 2R, 4R, 8R, 16R]$

In Fig. 3, the proposed schemes RSCM, RSCR, RSM and RSR are compared for code blocking probability performance which clearly indicates that RSCR provides minimum code blocking probability for uniform distribution scenario as it assigns scattered busy codes in scattered way using those codes for reassignment which provides zero or minimum new blocking of codes. Fig. 4 compares code blocking probability of other novel schemes like crowded first assignment CFA [8], quality based assignment (QB) [16] and recursive fewer block codes (RFCB) [21]. The RSCM scheme provides minimum code blocking as compared to these schemes. The numbers of code searches required before assignment in RSCM are comparable to FSP [20] which requires minimum number of code searches. The remaining schemes suffer from requirement of higher number of code searches before assignment. FSP [22] requires minimum number of codes searches before assignment but suffers from higher code blocking probability and DCA [10] provides zero code blocking but requires higher number of searches before assignment. Therefore, these schemes are not used for comparison in Fig. 4 and Fig. 5 respectively. The proposed schemes is easy to implement as compare to other schemes like DCA, CFA, RFCB and QB as their algorithm searches same codes recursively.

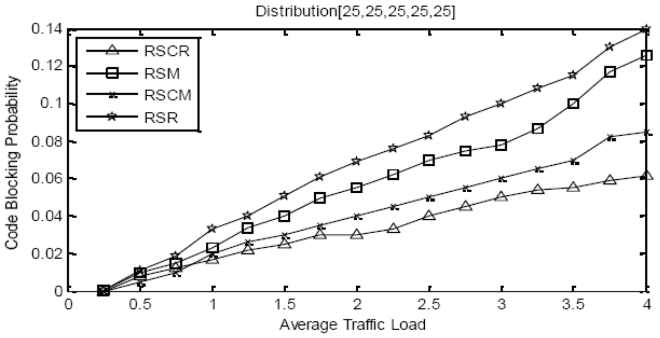


Figure 3: Code blocking probability comparison of proposed schemes for uniform distribution.

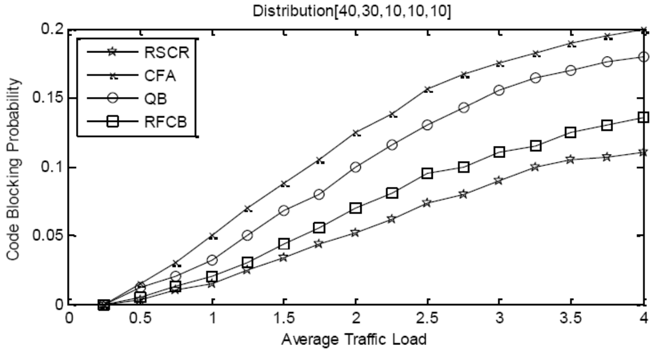


Figure 4: Code blocking probability comparison of proposed scheme with other novel schemes for uniform distribution.

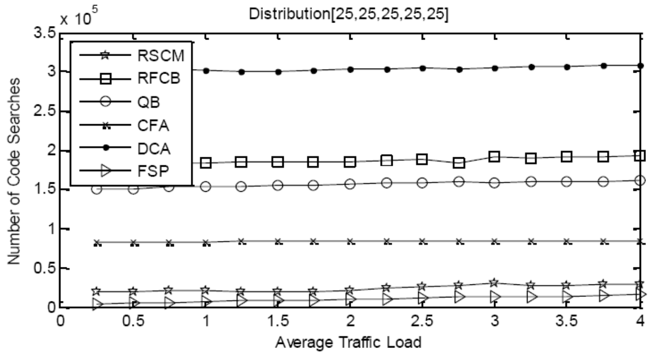


Figure 5: Number of Code Searches comparison of proposed scheme with novel schemes for uniform distribution.

CONCLUSION

Efficient utilization of available resources is an important issue for present and next generation wireless communication systems. In this paper, reassignment schemes are proposed which reduces code blocking probability and requires lesser call establishment delay for locating a vacant code. The schemes take the advantage of reassigning busy code(s) in offline mode when a call departs. This leads to minimum fragmentation of busy codes in the code tree and also reduces number of code searches during assignment process. To fit user's requirement the proposed RSCR scheme provides minimum code blocking probability and RSCM requires optimum code searches before assignment.

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