www.ietdl.org

Published in IET Communications
Received on 17th September 2013
Revised on 5th April 2014
Accepted on 1st May 2014
doi: 10.1049/iet-com.2013.0814

ISSN 1751-8628

Same rate and pattern recognition search of orthogonal variable spreading factor code tree for wideband code division multiple access networks

Vipin Balyan[1], *Davinder S. Saini*[2]

[1]*Department of Electronics and Communication Engineering, Jaypee Institute of Information Technology, Noida, Uttar Pradesh 2010307, India*
[2]*Department of Electronics and Communication Engineering, Jaypee University of Information Technology, Solan, Himachal Pradesh 173215, India*
E-mail: vipin.balyan@rediffmail.com

Abstract: Orthogonal variable spreading factor-based code division multiple access systems allocate vacant codes when new call (s) arrive. This study proposes a same rate assignment scheme which allocates a new call to most favourable code in the region crowded by same rate calls. This does not add to blocked codes because of previous calls but utilise the unused scattered capacity created by previous calls. A vacant code whose parent code is handling maximum number of ongoing calls of same rate is the most favourable code for new call assignment under that sub tree. This reduces higher rate blocking because of scattering of lower rate calls due to the fact that same rate calls will be assigned in the same portion of code tree. If a tie occurs for two parent codes it is resolved using pattern recognition of codes. In the proposed scheme, the most favourable search starts from higher layers that reduce number of code searches before assignment significantly. The proposed single code and multi code schemes are compared with other schemes based on code blocking probability, throughput and number of code searches required before assignment. Simulation results indicate that the proposed scheme outperforms other schemes for various traffic distributions.

Nomenclature

C_{m,n_m}	code in layer m and n_m denotes position in layer m
β_{m,n_m}	code rate matrix for C_{m,n_m}, containing information of assigned codes under its sub tree of layer $(m-1)$ to 1
$\beta^l_{m,n}$	number of codes of layer l assigned under sub tree of code C_{m,n_m}
γ^u_{m,n_m}	total used capacity of code C_{m,n_m}
γ^{un}_{m,n_m}	total unused capacity of code C_{m,n_m}
A^l_{j,n_j}	adjacency of code C_{j,n_j}
m	rakes
P_B	code blocking of ith class

1 Introduction

The 3G and beyond mobile communication networks provide a flexible support to handle multimedia traffic. UMTS/IMT-2000 is standard accepted for wireless system. The standard addresses the variable rate requirements of multimedia applications by using wideband code division multiple access (WCDMA) technology as the air interface [1, 2]. To support variable bit rate services, orthogonal variable spreading factor (OVSF) codes were proposed by 3GPP specifications [2] and are used as the channelisation codes to preserve orthogonality between different physical channels in WCDMA network. The OVSF codes are used in WCDMA networks to handle multi rate request of different calls. The spreading of signals depends upon spreading factor (SF). The chip rate of the system is given by SF × symbol rate = 3.84 Mcps. The OVSF-CDMA system can therefore provide multi rate services by assigning OVSF codes with a low SF to high-rate requests and high SF to low rate requests.

2 OVSF fundamentals

2.1 OVSF code tree structure

The OVSF codes can be represented by a binary tree [4]. The OVSF code tree is a binary tree with L layers, where a node represents a channelisation code C_{l,n_l}, $l = 1, 2, \ldots, L$, $n_l = 1, \ldots, 2^{L-1}$, l denotes layer number of code and n_l denotes its position in layer l. The codes in lowest layer are leaf codes and the code in highest layer is the root code. Let the capacity of the leaf codes (in layer 1) be R. The layer number decides the capacity of a code. The capacity of a code C_{l,n_l} in layer l is $2^{l-1}R$, $1 \le l \le L$, as illustrated in Fig. 1. The total capacity of all the codes in each layer is $2^{L-1}R$, irrespective of the layer number, the number of codes in layer l is 2^{L-1} and the SF of layer l is 2^{L-1}. An assigned parent code blocks all its children codes and vice

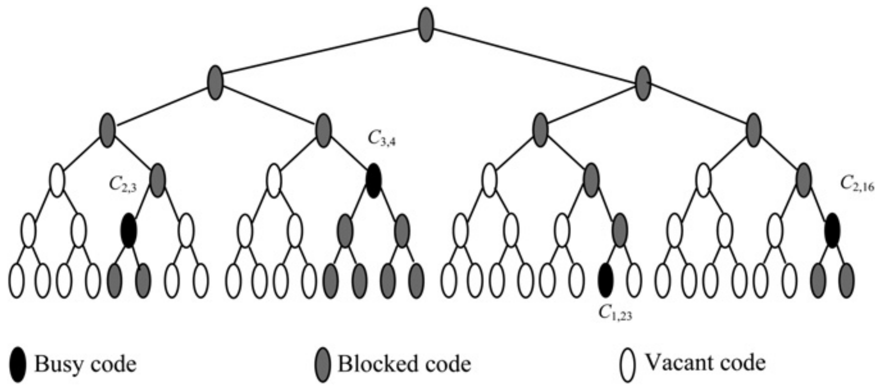


Fig. 1 *OVSF code tree with six layers*

versa. The effective and dynamic assignment of OVSF codes in maximising system throughput and reduction in code blocking is critical to the successful deployment of OVSF-CDMA systems.

2.2 Problem definition

The code blocking is explained using present status of Fig. 1, where the maximum capacity of the code tree is 32R. The used capacity is 9R (2R because $C_{2,3}$, 4R because $C_{3,4}$, R because $C_{1,23}$ and 2R because $C_{2,16}$). The remaining vacant capacity of the code tree is (32-9) $R = 23R$. If a new call with rate 16R arrives, system does not support it because there is no vacant code with capacity 16R. This occurs because of external fragmentation and produces code blocking. The other cause of code blocking is internal fragmentation. This is because of the quantised rate handling capability of OVSF code tree. If a new user with rate kR, $k \neq 2^n$ arrives, the user requires a code with capacity $2^m R$, where $k < 2^m$ for minimum m. For example, a code of 16R rate is assigned to a call request of 12R. The capacity 4R (16R–12R) which is 33% of the required capacity is wasted. This wastage will further increases with increase in difference of requested call rate and assigned code rate. One way to reduce wastage is to use multiple codes which may increase the complexity, cost of the base station (BS) and mobile station.

2.3 Related work

In literature, a number of code assignment schemes are proposed to reducing code blocking probability. The performance of OVSF-CDMA can be improved using efficient code assignment and reassignment schemes [3]. These schemes can be arranged in various categories. The single code assignment scheme [4] uses one code from the OVSF code tree to handle new call. The single code usage requires single rake combiner in the BS and user equipment (UE). The multi-code assignment scheme [5] uses multiple codes to handle quantised or non-quantised data rates. This requires same number of rake combiners as the codes used to handle new call which increases complexity. Crowded first assignment (CFA) [6], leftmost code assignment (LCA) [6], fixed set partitioning (FSP) [7] and recursive fewer codes blocked (RFCB) scheme [8] are few popular single code assignment schemes. In CFA, the code assignment is carried out to serve higher rate calls better in future. It has two categories namely crowded first code (based upon number of busy children) and crowded first capacity (based upon children used capacity). In LCA, code assignment is carried out from left side of the OVSF code tree. In FSP, the code tree is divided into a number of sub trees according to the number of input traffic classes and their distribution. The RFCB scheme works on the top of CFA and optimum code is the one which makes least number of higher rate codes blocked. It resolves tie by recursively searching for best candidate. The adaptive code assignment (ADA) [9] scheme divides the tree into small portions according to call arrival distribution. Consequently, the number of codes searched for new calls obtains reduced. The dynamic code assignment (DCA) scheme in [10] handles new call using code reassignments. This is the best single code scheme to reduce code blocking but the cost and complexity in reassignments is too high which limits its usage for low to medium traffic conditions. DCA is further improved to reduce complexity and to increase scalability by capacity partitioning and class partitioning [11] methods. The computationally efficient dynamic code assignment with call admission control (DCA–CAC) reduces complexity of traditional DCA in two different ways: (a) total resources are divided into number of mutually exclusive groups, with number of groups equal to number of call arrival classes; and (b) by deliberate rejection of those calls which may produce large code blocking for future higher rate calls. The number of code searched [12–13] has direct impact on delay or speed of the code assignment and can have significant impact on delay prone services like speech transmission and video conferencing and so on. The fast DCA [14] reduces the number of code reassignments without causing degradation in the spectral efficiency of system. The rearrangeable (dynamic) approach [15] 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 [16, 17], 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. The multi code multi rate assignment [18] scheme takes into consideration mobile devices with different multi code transmission capabilities and different quality of service parameters. The multi code scheme with code sharing [19] is suggested to reduce wastage capacity or code blocking. It combines scattered capacity (children codes of assigned codes) of already assigned codes to reduce code blocking problem. The multi code scheme [20] formulates the optimum number of codes/rakes required to handle new call. The assignment scheme proposed in [21] investigates the impact of remaining time on the performance of the OVSF codes. Two time-based allocation schemes are proposed, and both consider remaining time as primary factor in code assignment and reassignment. The calls with approximately same amount of remaining time are allocated in the same sub tree. The calls with similar remaining time are allocated to the same sub tree. The non-blocking OVSF (NOVSF) codes given in [22–24] minimise the code blocking to zero. The code usage time is converted into multiple time slots and any one layer is sufficient to handle calls with variable rate requirements. The cost and complexity of the NOVSF codes is very high. The scattering is reduced by handling non-quantised calls using multi codes in [25].

The rest of this paper is organised as follows. Section 3 explains proposed same rate assignment (SRA) scheme. Result and simulations are given in Section 4. Finally, the paper is concluded in Section 5.

3 Proposed scheme

3.1 Single code assignment: same rate assignment

To improve code blocking probability and call establishment delay in OVSF-based CDMA network used for communication, this paper proposes a SRA scheme which assigns OVSF codes efficiently to reduce code blocking probability requiring less call establishment delay to locate most favourable vacant code. 'The most favourable code is one which will lead to least code blocking and less call establishment delay'. Consider an OVSF-based WCDMA tree of L layer ($L = 8$). The SRA scheme concept of most favourable selection is done in three levels.

Level I: finding most favourable code for assignment using defined parameters.
Level II: if a tie occurs in level I, a tie is resolved using pattern search.
Level III: code rate matrix updation after levels I and II.

3.1.1 Level I: same rate assignment:

In level I, a code rate matrix is defined for every code in code tree as $\beta_{m,n_m} = \left[\beta^{m-1}_{m,n_m}, \ldots, \beta^{1}_{m,n_m}\right]$, where β_{m,n_m} (contains the information of number of assigned codes of each layer (different rates) below it and $1 \le n_m \le 2^{L-m}) \forall C_{m,n_m}$. For example, $\beta^{L-1}_{m,n_{L-1}}$, stores the information of codes assigned to ongoing calls of rate $2^{L-2}R$ and β^{1}_{m,n_1}. Also, $\sum_{j=1}^{L-2} \beta^{j}_{m,n_j} \times 2^{j-1}R$ represents total capacity busy under code $C_{L-1,\, n}$, where $1 \le n \le 2$.

For an incoming call request of rate $2^{l-1}R$, $1 \le l \le L$, the SRA scheme searches most favourable code by comparing the status of code rate matrix element corresponding to rate $2^{l-1}R$, that is, β^{l}_{m,n_m} is checked in higher layer from $(l+1)$ to $(l+3)$ $(l+1) \le m \le (l+4)$. The procedure of the most favourable code selection is shown with the help of an algorithm.

1. ***If*** $\gamma^{u}_{L,1} \le 2^{L-1}R$
2. The SRA scheme determines whether the used capacity of sub tree under code(s) $C_{m,nm}$, $m = (l+4)$ added with the incoming call required rate is less than or equal to total capacity of those codes.

Find used capacity under codes $C_{m,nm}$ or used capacity of $C_{m,nm}$

$$\gamma^{u}_{m,n_m} = \beta^{m-1}_{m,n_m} \times 2^{m-2}R + \beta^{m-2}_{m,n_m} \times 2^{m-3}\,R + \cdots + \beta^{1}_{m,n_m} \times 1R$$
$$= \sum_{j=1}^{m-1} \left(\beta^{m-j}_{m,n_m} \times 2^{m-j-1}\right)R \quad (1)$$

Unused capacity of C_{m,n_m}

$$\gamma^{un}_{m,n_m} = 2^{m-1}R - \sum_{j=1}^{m-1} \left(\beta^{m-j}_{m,n_m} \times 2^{m-j-1}\right)R \quad (2)$$

Therefore if $\sum_{j=1}^{m-1} (\beta^{m-j}_{m,n_m} \times 2^{m-j-1})R + 2^{l-1}R \le \gamma^{\max}_{m,n_m}$ then a call will be supported by code C_{m,n_m} for most favourable code selection.
3. Find code C_{m,n_m}, $m = (l+4)$, with max $\left(\beta^{l}_{m,n_m}\right)$. If more than one code with max (β^{l}_{m,n_m})exists tie occurs and is resolved using 'pattern recognition (PR) of busy codes' under C_{m,n_m} sub tree as explained in level II.
4. For a single code available with max (β^{l}_{m,n_m}), the most favourable code is selected by virtually dividing sub tree into two equal parts $\forall$layers$(l+1) \le m' \le (l+3)$ and code selection procedure selects max $(\beta^{l}_{m',n_{m'}})$ and call is assigned to the vacant code whose immediate parent has max $(\beta^{l}_{m',n_{m'}})$.
5. If two or more codes at layer m contains same number of busy codes of rate $2^{l-1}R$, a tie occurs go to level II.
6. ***Else***
Block call.
7. ***End***

3.1.2 Level II: Tie resolving by PR:

If a tie occurs at jth layer, then most favourable code search jumps from jth to lth layer. For all codes $C_{j,\, nj}$, where $(l+1) \le j \le (l+4)$, 'pattern' of codes C_{l,n_l}will be searched, where $n_l = 2^{j-l} \times (n_j - 1) + k$, and $0 \le k \le (2^{j-1} - 1)$. The searched will be from $C_{2^{j-l} \times (n_j-1)}$ to $C_{2^{j-l} \times (n_j-1)+2^{j-1}-1}$. The pattern for a sub tree of 4 and 8 codes of C_{j,n_j} is given in Figs. 6 and 7*a*, *b* in the Appendix for different number of busy codes. The patterns in Figs. 6 and 7*a*, *b* are formed after considering acceptance of new call of rate $2^{l-1}R$, that is, one of the code is assigned to new call. The pattern of busy (rate $= 2^{l-1}R$) children codes of both codes will be compared using Tables 2 and 3, the one which will lead to minimum code blocking after assigning vacant code will be selected ('A blocked code is treated as vacant code in forming pattern. Adjacent codes in scheme are those codes which have same parents in all layers'.).

1. **If** $(j-l) \le 4$
2. Search the sub tree of all C_{j,n_j}codes in layer l and find maximum adjacent busy codes of rate $2^{l-1}R$, if for any busy code any parent is different, then it will not be included to find adjacency denoted by A^{l}_{j,n_j}.
3. Arrange codes $C_{j,n_j}$with descending value of A^{l}_{j,n_j}.
4. Pick first two codes $C_{j,n_j}$with higher $\left(A^{l}_{j,n_j}\right)$.
5. *If* $\left|\left(A^{l}_{j,n_j}\right)_1 - \left(A^{l}_{j,n_j}\right)_2\right| \le 2$, check the pattern of codes as given in Figs. 6 and 7*a*, *b* and select the pattern which will

doi: 10.1049/iet-com.2013.0814

lead to maximum utilisation of scattered codes for assignment to new call. The pattern preference is also explained in the Appendix.

6. *else if* $\left|\left(A^{l}_{j,n_j}\right)_1 - \left(A^{l}_{j,n_j}\right)_2\right| \geq 3$ assign new call to code with adjacency $(A^{l}_{j,n_j})_1$.
7. *else if* $\left|\left(A^{l}_{j,n_j}\right)_2 - \left(A^{l}_{j,n_j}\right)_1\right| \geq 3$ assign new call to code with adjacency $\left(A^{l}_{j,n_j}\right)_2$.
8. *End.*
9. **Else if** $(j-l) > 4$

Then $\forall C_{j,n_j}$ code, children's pattern are searched separately. For a code C_{j,n_j}, the children are denoted by $C_{j_c,(2n_{j_c}+i)}$, where $1 \leq i,\ c \leq 2$, c denotes the codes with a tie. It denotes there only one parent code is same. If the children code $C_{j_c,(2n_{j_c}+1)}$ has adjacency $A^{l}_{j_c,(2n_{j_c}+1)} = 2^{j-l}$, then total adjacency of $C_{j_c,(2n_{j_c}+2)}$ will be $A_{j_c,(2n_{j_c}+1)} + A_{j_c,(2n_{j_c}+2)}$, that is, $A^{\text{new}}_{j_c,(2n_{j_c}+2)} = 2^{j-l} + A_{j_c,(2n_{j_c}+2)}$.

10. Repeat step 5 to 9.
11. **End**

This scheme starts most favorable code search from $(l+4)$th layer. If initially or any particular duration of time code tree is not handling any call of rate equal to rate of incoming call, then call will be assigned to left most vacant code.

3.1.3 Level II: code rate matrix updation after levels I and II: Code rate matrix is updated periodically when a call is accepted and ends. If a call of rate $2^{l-1}R$ is accepted then code rate matrix corresponding element β^{l}_{k,n_k}, $\forall k$, $(l+1) \leq k \leq (L-1)$ is updated by '1' and decremented by '1' when call ends. If status of $\beta^{l}_{l+1,n_{l+1}} = 1$, when a call of rate $2^{l-1}R$ accepted, the total capacity $2^{l}R$ of code $C_{l+1,n_{l+1}}$ is assigned, then update $\forall \beta^{l}_{k,n_k}$, $(l+1) \leq k \leq (L-1)$ as $\beta^{l}_{k,n_k} = \left(\beta^{l}_{k,n_k} - 1\right)$ and $\beta^{l+1}_{k,n_k} = \left(\beta^{l+1}_{k,n_k} + 1\right)$.

This scheme performs better than existing assignment schemes as:

(1) it provides significant improvement in code blocking probability because of the assignment of new call of rate $2^{l-1}R$ to that sub tree which has maximum number of $2^{l-1}R$ rate calls. It selects that portion of the code tree which is already blocked by same rate ongoing calls. In other words, it increases utilisation of blocked codes and will improve spectral efficiency of code tree. Eventually, a virtual partition in code tree is created of same rate calls in same sub tree;
(2) it provides less number of code searches as code search starts from $(l+4)$ layer to $(l+1)$. This directly influence call establishment delay. Code rate matrix can also be used for finding total capacity used/unused of every code which is used in case of tie and will reduce code searches too.

3.2 Same rate fraction multi code assignment

If a call is not handled using single code, and if the system is equipped with m rakes, then there are two ways for multi code assignment.

3.2.1 First method: assignment using m rakes: For an incoming call of rate $2^{l-1}R$, break call into m fractions such that each fraction is quantised, that is, $\sum_{i=1}^{m} r(i) = 2^{l-1}R$, where r denotes rate of ith rake. It will efficiently utilise resources associated with rakes but will lead to higher scattering when call end which is utilising all rakes. For illustration, consider status of code tree in Fig. 2. For an incoming call of rate $16R$, as no single code of rate $16R$ is available call will be blocked using single code assignment. Using same rate fraction multi code if system is

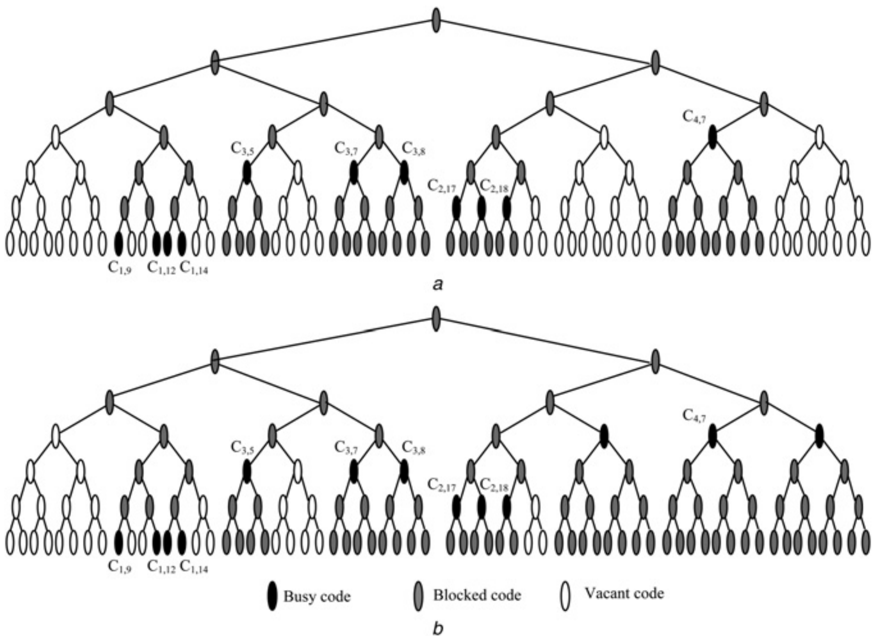


Fig. 2 *Multi code assignment using same rate fraction*
a Code tree status when first call of $16R$ arrives
b Code tree status when second call of $16R$ arrives

Table 1 Simulation parameters

Parameter	Value/range
user classes	R, $2R$, $4R$, $8R$, $16R$
arrival rate (λ) is Poisson distributed	mean value varying from 0 to 4 calls/min
call duration ($1/\mu_i$) is exponentially distributed	mean value of 3 min
total capacity of code tree	$128R$ (R = 7.5 kbps)
number of users	10 000
results average	10
arrival rate and service rate for ith 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	$[p_1, p_2, p_3, p_4, p_5] = [p_i]$, $i \in [1, 5]$

equipped with four rakes, break call into rakes fractions either ($8R$, $4R$, $2R$, $2R$) or ($4R$, $4R$, $4R$, $4R$) or ($8R$, $4R$, $2R$, $2R$). The code tree is searched using SRA in Section 3.1 and is assigned to the vacant codes available for any of the rate fractions. The priority for multi code assignment is (i) $8R$, $4R$, $2R$, $2R$), (ii) ($4R$, $4R$, $4R$, $4R$) and (iii) ($8R$, $4R$, $2R$, $2R$).

3.2.2 Second method: assignment using $2 \leq r \leq m$ rakes: Break incoming call rate into fractions of descending rate and search vacant codes for those rate fractions, that is, $\sum_{i=1}^{t} r(i) = 2^{l-1}R$, $t \leq m$. Search code for rate fraction as explained in Section 3.1. The multi code algorithm work as follows:

(1) Divide incoming call rate into two equal rate fractions.
(2) Search vacant codes using same rate assignment for both rate fractions as in Section 3.1.
(3) *If*
Vacant code available for one or both rate fractions, use them or assign them to new call rate.
(4) *Else if* (number of rakes > number of ratefractions)
Go to step 1.
(5) Else
Block Call.
(6) End

For illustration consider status of code tree in Fig. 2. For an incoming call of rate $16R$, as no single code of rate $16R$ is available call will be blocked using single code assignment. Using same rate fraction multi code, call can still be

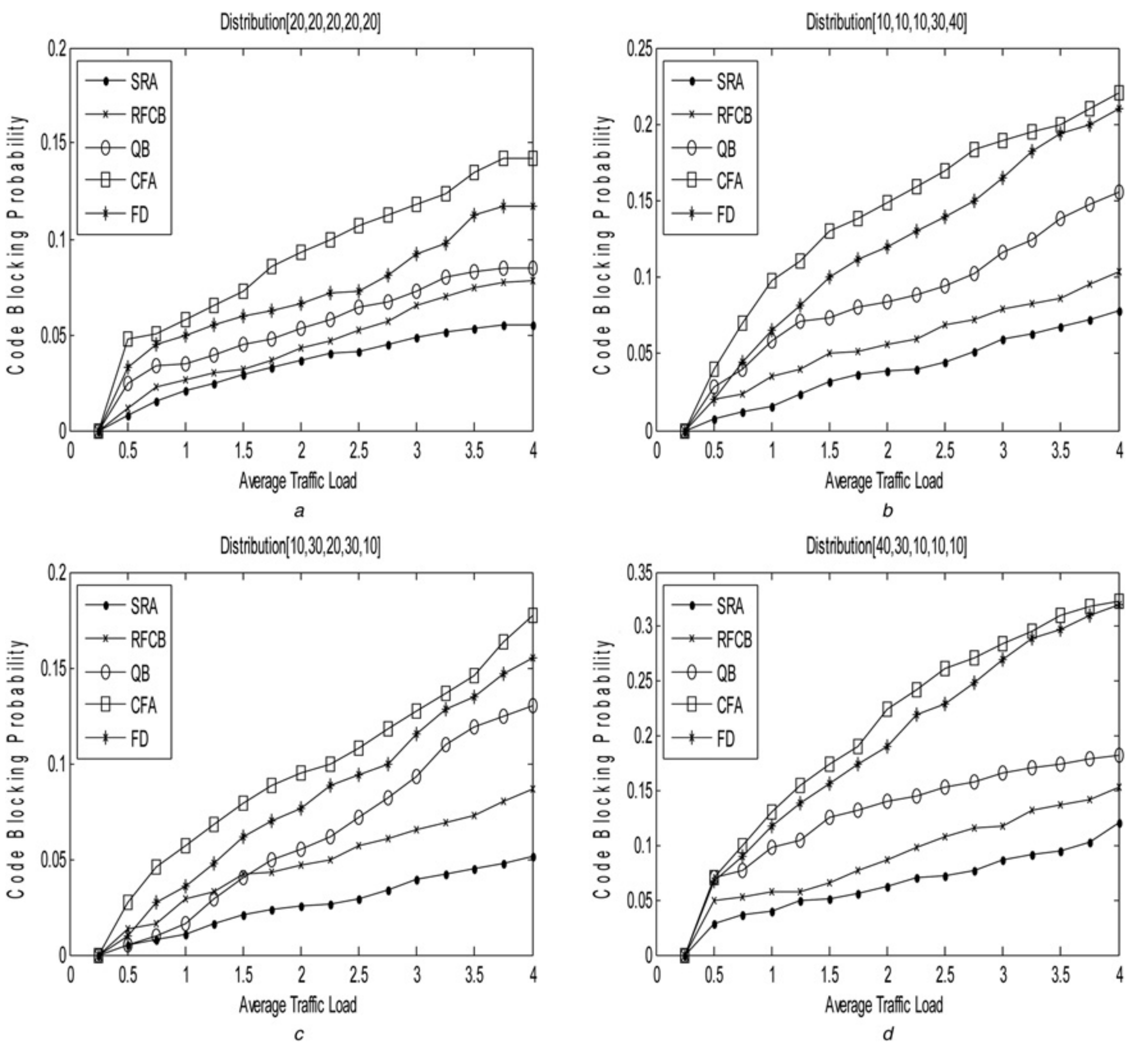


Fig. 3 *Comparison of code blocking probability in single code schemes for distribution*

a [20, 20, 20, 20, 20]
b [10, 10, 10, 30, 40]
c [10, 30, 20, 30, 10]
d [40, 30, 10, 10, 10]

IET Commun., 2014, Vol. 8, Iss. 13, pp. 2366–2374
doi: 10.1049/iet-com.2013.0814

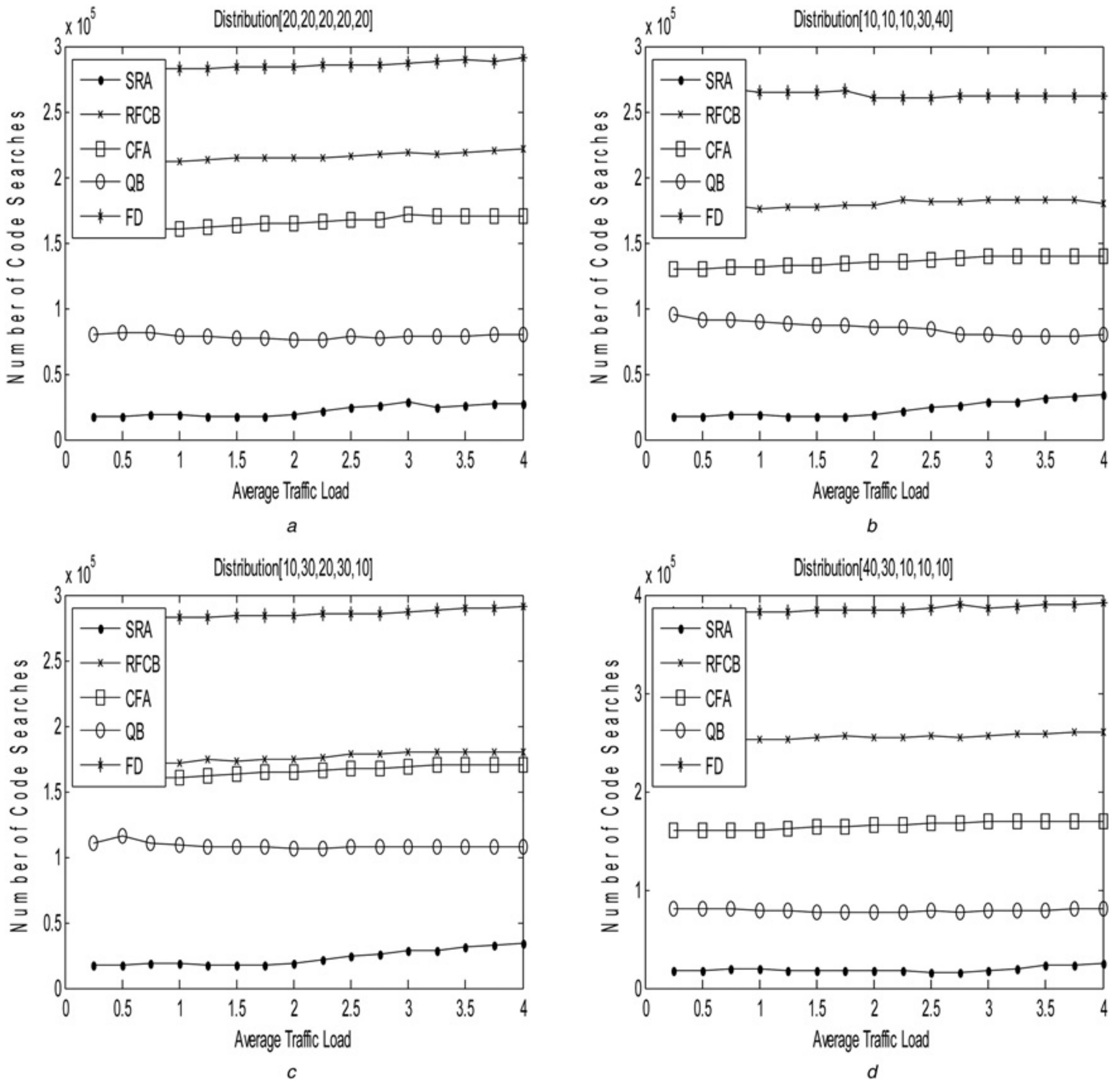


Fig. 4 *Comparison of number of code searches in single code schemes for distribution*
a [20, 20, 20, 20, 20]
b [10, 10, 10, 30, 40]
c [10, 30, 20, 30, 10]
d [40, 30, 10, 10, 10]

handled. Divide $16R$ into two $8R$ rate fractions using two rakes and search a vacant code for each of them using same rate fraction assignment. Two rate fractions will be treated as new calls and using same rate fraction $C_{4,8}$ and $C_{4,6}$ are most favourable code in Fig. 2*a* for $8R$ fractions in first and second search, respectively. Call of $16R$ will be assigned to vacant codes $C_{4,8}$ and $C_{4,6}$. If another call of $16R$ arrives for the status of the code tree in Fig. 2*b*, call cannot be handled using two rakes. One vacant code of rate $8R$ ($C_{4,1}$) is available, another $8R$ is again divided into two $4R$ using two rakes and vacant codes are searched using same rate fraction assignment. $C_{3,6}$ is the only available vacant code available, therefore more rakes are utilised to break another $4R$ into two equal parts using two more rakes. $C_{2,19}$ and $C_{2,8}$ are two most favourable codes of rate $2R$ and call is handled using these codes.

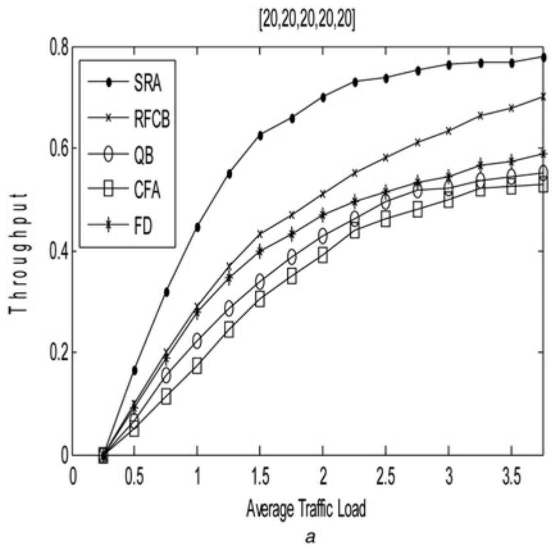
3.3 Fairness issue of same rate assignment

For a traffic load with L' classes and total capacity of code tree is $2^{L-1}R$, $L = 8$. The code tree provides fairness to all incoming call classes, if total capacity of code tree is divided equally among all L' classes such that capacity for each class is $2^{L-1}R/L'$. If total capacity of any class is already assigned to ongoing calls, then a new call of that rate is blocked. The capacity assigned to a class is checked by adding $\sum_{i=1}^{2} \beta_{L-1,i}^{l}$ and if $\sum_{i=1}^{2} \beta_{L-1,i}^{l} = 2^{L-1}/L'$, then block new call of rate $2^{L-1}R$. This will further reduced total call establishment time by limiting number of code searches at the cost of higher code blocking.

4 Simulations and results

The simulation parameters are given in Table 1. Four 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 $16R$ will be requested after 16 calls of rate R, 8 calls of $2R$, 4 calls of rate $4R$ and 2 calls of rate $8R$.

- [20, 20, 20, 20, 20]: Capacity of each rate is uniform.
- [10, 10, 10, 30, 40]: Capacity of high rate calls dominating.



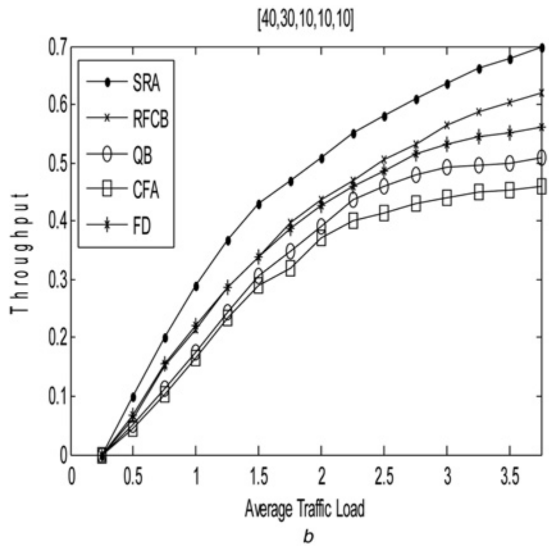


Fig. 5 *Throughput comparison of single code schemes*
a Uniform rate distribution [20, 20, 20, 20, 20]
b Low rate dominating distribution [40, 30, 10, 10, 10]
Distribution scenario

- [10, 30, 20, 30, 10]: Capacity of medium rate calls dominating.
- [40, 30, 10, 10, 10]: Capacity of low rate calls dominating.

The average code blocking for a five class system is defined as

$$P_B = \sum_{i=1}^{5} (\lambda_i P_{B_i}/\lambda) \tag{3}$$

where $\boldsymbol{P_{B_i}}$ is the code blocking of ith class and is given by

$$\boldsymbol{P_{B_i}} = \frac{\rho_i^{G_i}/G_i!}{\sum_{n=1}^{G_i} \rho_i^n/n!} \tag{4}$$

In this paper, the performance of the proposed scheme is compared with FSP, LCA, CFA, RFCB, quality based (QB) [26] and fixed dynamic (FD) [27] schemes available in literature. The code blocking probability is shown in Fig. 3. FSP and LCA schemes suffer from high code blocking probability. Therefore plot is not shown for comparison with them for proposed scheme. However, code blocking probability for RFCB and QB schemes is comparable to the proposed scheme, but the code searches are higher as shown in Fig. 4. SRA also outperforms CFA and FD schemes. SRA provides least code blocking probability as it blocks only those codes which are blocked by previous calls of same rate. The throughput performance for the proposed scheme is also compared for uniform and low rate calls dominating distribution in Fig. 5. FSP and LCA blocks highest number of new call requests and the throughput of these schemes is very low. The throughput in FSP and LCA is poor because, while in FSP scheme, fixed portion of code tree is searched for new request resulting in call blocking when vacant code is not available, and in LCA scheme call is assigned to the first available vacant code leading to code scattering and code blocking.

For low rate dominating call scenario, the proposed scheme provides improvement in code blocking. On the other hand, and for high rate dominating scenario, the scheme requires less number of code searches before assignment with nominal code blocking. The multi code enhancement of the scheme leads to further reduction in code blocking and higher number of code searches as compared to single code schemes.

5 Conclusion

Real time calls are prone to least call establishment delay. The proposed SRA scheme reduces code blocking and requires less call establishment delay when a new call arrives. The SRA scheme reduces call establishment delay without compromising the throughput performance. The performance of the proposed scheme is not influenced by the incoming call distribution; it utilises code tree capacity and provides almost similar results for all type of traffic distributions. Work can be done in future considering interference limited environment because of neighbouring cells using same frequency and for *ad-hoc* networks.

6 References

1 Adachi, F., Sawahashi, M., Suda, H.: ‘Wideband CDMA for next generation mobile communications systems’, *IEEE Commun. Mag.*, 1998, **36**, (9), pp. 56–69
2 3rd Generation Partnership Project (3GPP), Technical Specification Group (TSG), Spreading and Modulation (FDD), TS 25.213 V3.8.0, June 2002
3 Saini, D.S., Bhoosan, S.V.: ‘Code tree extension and performance improvement in OVSF-CDMA systems’. Proc. Int. Conf. IEEE, ICSCN 2007, 2007, pp. 316–319
4 Hwang, R.H., Chang, B.J., Chen, M.X., *et al.*: ‘An efficient adaptive grouping for single code assignment in WCDMA mobile networks’, *Wirel. Pers. Commun.*, 2006, **39**, (1), pp. 41–61
5 Chang, B.J., Chang, P.S.: ‘Multicode-based WCDMA for reducing waste rate and reassignments in mobile cellular communications’, *Comput. Commun. J.*, 2006, **29**, (11), pp. 1948–1958
6 Tseng, Y.C., Chao, C.M., Wu, S.L.: ‘Code placement and replacement strategies for wideband CDMA OVSF code tree management’. Proc. Int. Conf. IEEE GLOBECOM’01, 2001, pp. 562–566
7 Park, J.S., Lee, D.C.: ‘Enhanced fixed and dynamic code assignment policies for OVSF-CDMA systems’. Proc. Int. Conf. ICWN 2003, 2003, pp. 620–625

doi: 10.1049/iet-com.2013.0814

8 Rouskas, A.N., Skoutas, D.N.: 'Management of channelization codes at the forward link of WCDMA', *IEEE Commun. Lett.*, 2005, **9**, pp. 679–681
9 Saini, D.S., Bhoosan, S.V.: 'Adaptive assignment scheme for OVSF codes in WCDMA'. Proc. Int. Conf. IEEE ICWMC, 2006, p. 65
10 Minn, T., Siu, K.Y.: 'Dynamic assignment of orthogonal variable-spreading-factor codes in WCDMA', *IEEE J. Sel. Areas Commun.*, 2000, **18**, (8), pp. 1429–1440
11 Park, J.S., Huang, L., Kuo, C.C.J.: 'Computationally efficient dynamic code assignment schemes with call admission control (DCA-CAC) for OVSF-CDMA systems', *IEEE Trans. Veh. Technol.*, 2009, **57**, pp. 286–296
12 Askari, M., Saadat, R., Nakhkash, M.: 'Comparison of various code assignment schemes in wideband CDMA'. Proc. Int. Conf. IEEE on Computer and Comm. Engineering, 2008, pp. 956–959
13 Saini, D.S., Kanwar, S., Parikh, P., *et al.*: 'Vacant code searching and selection of optimum code assignment in WCDMA wireless network'. Proc. Int. Conf. IEEE NGMAST, 2009, pp. 224–229
14 Wan, C.S., Shih, W.K., Chang, R.C.: 'Fast dynamic code assignment in next generation wireless access network', *Comput. Commun. J.*, 2003, **26**, pp. 1634–1643
15 Amico, M.D., Merani, M.L., Maffioli, F.: 'Efficient algorithms for the assignment of OVSF codes in wideband CDMA'. Proc. Int. Conf. ICC 2002, 2002, pp. 3055–3060
16 Fantacci, R., Nannicini, S.: 'Multiple access protocol for integration of variable bit rate multimedia traffic in UMTS/IMT-2000 based on wideband CDMA', *IEEE J. Sel. Areas Commun.*, 2000, **18**, pp. 1441–1450
17 Fossa, C.E., Davis, N.J.: 'Dynamic code assignment improves channel utilization for bursty traffic in third-generation wireless networks'. Proc. Int. Conf. IEEE ICC'02, 2002, pp. 3061–3065
18 Yang, Y., Yum, T.S.P.: 'Multicode multirate compact assignment of OVSF codes for QoS differentiated terminals', *IEEE Trans. Veh. Technol.*, 2005, **54**, pp. 2114–2124
19 Saini, D.S., Bhoosan, S.V.: 'OVSF code sharing and reducing the code wastage capacity in WCDMA', *J. Wirel. Pers. Commun.*, 2009, **48**, pp. 521–529
20 Saini, D.S., Upadhyay, M.: 'Multiple rake combiners and performance improvement in WCDMA systems', *IEEE Trans. Veh. Technol.*, 2009, **58**, (7), pp. 3361–3370
21 Cheng, S.T., Hsieh, M.T.: 'Design and analysis of time-based code allocation schemes in W-CDMA systems', *IEEE Trans. Mob. Comput.*, 2005, **4**, pp. 3103–3112
22 Vadde, K., Qam, H.: 'A code assignment algorithm for nonblocking OVSF codes in WCDMA', *J. Telecommun. Syst.*, 2004, **25**, (3), pp. 417–431
23 Qam, H.: 'Non-blocking OVSF codes and enhancing network capacity for 3G wireless and beyond systems', *J. Comput. Commun.*, 2003, pp. 1907–1917
24 Qam, H., Vadde, K.: 'Performance analysis of nonblocking OVSF codes in WCDMA'. Proc. Int. Conf. Int. Conf. on Wireless Networks, 2002, pp. 204–215
25 Saini, D.S., Sharma, N.: 'Reduction in code blocking using scattered vacant codes for orthogonal variable spreading factor-based wideband code division multiple access networks', *IET Commun.*, 2013, **7**, (1), pp. 40–48
26 Wan, C.S., Shih, W.K., Chang, R.C.: 'Fast dynamic code assignment in next generation wireless access network', *Comput. Commun.*, 2003, **26**, pp. 1634–1643
27 Tsai, Y.R., Lin, L.C.: 'Quality-based OVSF code assignment and reassignment strategies for WCDMA systems', *IEEE Trans. Veh. Technol.*, 2009, **58**, (2), pp. 1027–1031

7 Appendix

When a tie occurs at a layer j, it is resolved using pattern search of codes assigned to ongoing calls of rate $2^{L-1}R$ at layer l. If number of codes under sub tree where tie occurs are 4 a code is selected using Fig. 6 and Table 2 and if 8 codes exists then using Figs. 7*a* and *b* and Table 3. In Figs. 7*a* and *b*, number of codes assigned are shown under it as 7, 5, 6 and so on. Table 2 is constructed using pattern of Figure 6, column 1 contains assigned code with similar pattern, column 2 there adjacency and order of preference. Table 3 is constructed using pattern of Figs. 7*a* and *b*, column 1 contains assigned code pattern which will lead to similar (a) code blocking, (b) scattering of vacant codes and (c) utilisation of higher layer (parent) codes. Column 2 contains number of codes assigned to ongoing calls (including new call), column 3 contains number of codes/ blocked of levels 1 and 2. Adjacency of codes, scattered/ vacant codes (layer 1 above) and their preference calculated in columns 4, 5 and 6, respectively. The order of preference is based on adjacency. However, if two codes have same adjacency, then column 3 is used to resolve the tie. Check the number of codes they are utilising/ blocking of levels 1 and 2. The most favourable code is one which is blocking least higher number of codes of layers 2 and 1, respectively, or the one utilising the wastage capacity of higher layer code(s). This will lead to least blocking of higher rate calls in future.

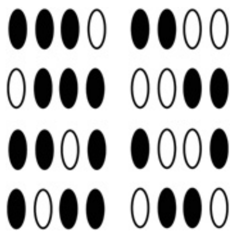


Fig. 6 *Pattern of four codes sub tree after accepting new call*

Table 2 For four codes sub tree, blocked code, adjacency and their preference

Blocked code	Adjacency	Order of preference
A1-A2	3	A1-A2
A3-A4	2	A3-A4
B1-B2	2	B1-B2
B3-B4	0	B3-B4

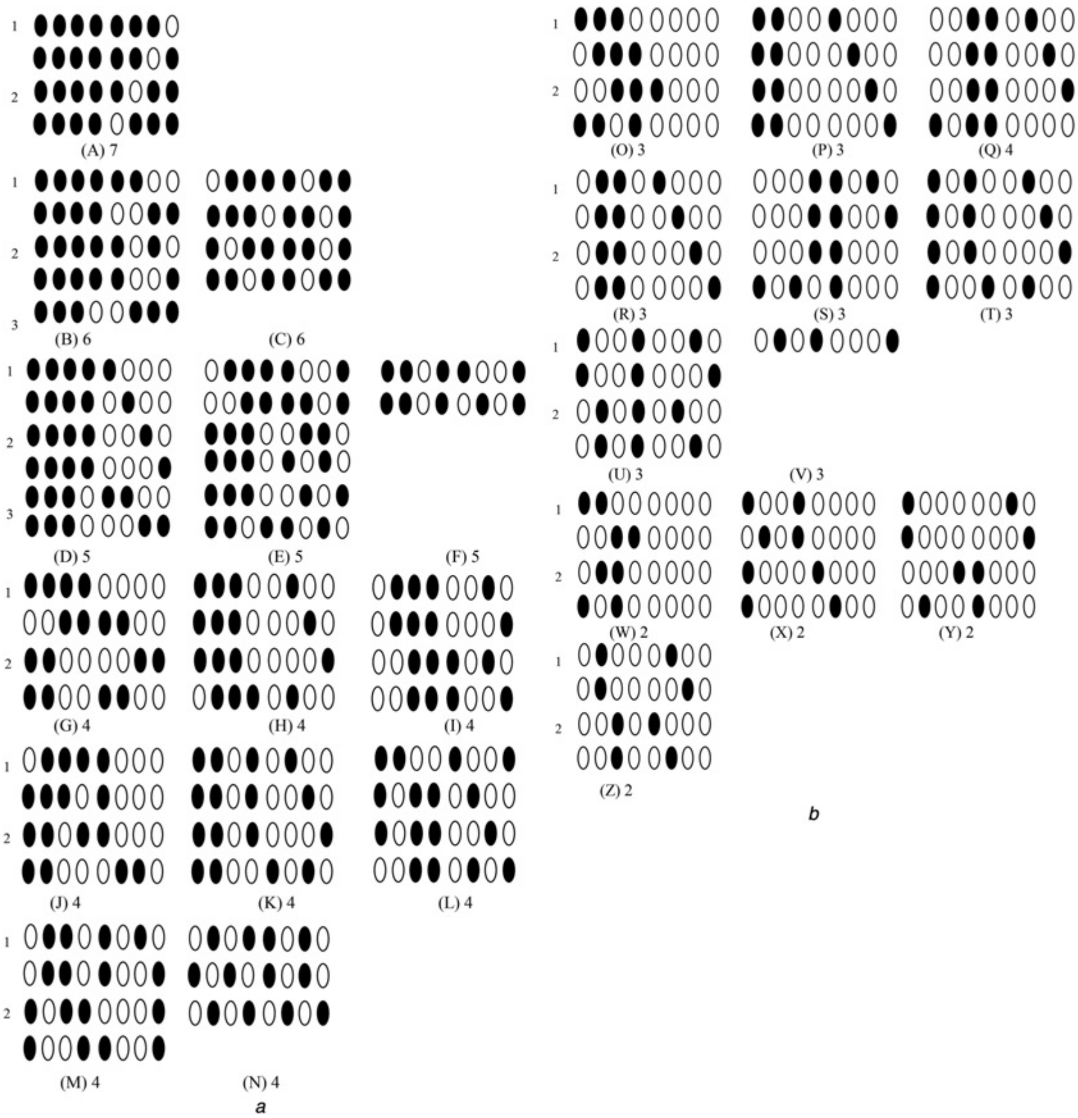


Fig. 7 *Eight codes in a layer exists*

a Pattern for assigned codes 7(A), 6(B, C), 5(D–F) and 4(G–N)
b Pattern for assigned codes 3(O–V), and 2(W, Z)

Table 3 Comparison of codes blocked, utilised and adjacency with different assigned codes

Pattern	Number of codes assigned	No. of codes used/blocked/vacant after assignment till next two levels/layers		Adjacency	Vacant/ scattered codes	Order of preference
		Level 1	Level 2			
A1-A4	7	3U/1B	1U/1B	7-6-5-4	1	A1-A4
B1-B2	6	3U	1U/1B	6-4	2	B1-B2
B3-B4, B5-C4		2U/2B	1U/1B	5	2S	B3-B4
		2U/2B	1U/1B	3-3-3-2-2	2S	B5-C4
D1-D4	5	2U/1B	1U/1B	5-4-4-4	2, 1S	D1-D4
D5-D6		2U/1B	2B	3	2, 1S	D5-D6
E2		2U/1B	2B	2	2, 1S	E2
E1, E3-E5		1U/3B	2B	3	3S	E1, E3-E5
F1-F2		1U/3B	2B	2	3S	F1-F2
G1	4	2U	1U	4	4	G1
G2-G4		2U	2B	2	2, 2	G2-G4
H1-I2, J1-J2		1U/2B	2B	3	2, 2S	H1-I2, J1-J2
J3-L4, M3		1U/2B	2B	3	2, 2S	J3-L4, M3
M1-M2, M4-N4		4B	2B	0	4S	M1-M2, M4-N4
O1-O2	3	1U/1B	1B	3	4, 1S	O1-O2
O4, Q4		1U/1B	1B	2	4, 1S	O4, Q4
O3, P1-Q3		1U/1B	2B	2	2, 2, 1S	O3, P1-Q3
R1-V1		3B	2B	0	2, 3S	R1-V1
W1-W2	2	1U	1B	2	6	W1-W2
W3-X2		2B	1B	0	4, 2S	W3-X2
X3-Z4		2B	2B	0	2, 2, 2S	X3-Z4

doi: 10.1049/iet-com.2013.0814