A Fast Code Assignment Strategy for W-CDMA Rotated-OVSF Tree with Code-Locality Capability

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Abstract

In this paper, a new channelization code scheme, namely ROVSF (Rotated-Orthogonal Variable Spreading Factor), is developed to quickly seeking available codes, compared to using the conventional OVSF (Orthogonal Variable Spreading Factor) in the WCDMA system. When new call enters the system, the OVSF-based scheme always takes lots of time to search for a feasible code. Our ROVSF-based scheme provides a fast code assignment strategy based on new proposed code tree structure. Observe that, our ROVSF scheme offers the same code capability with the OVSF-based schemes, and inherited most of the properties of OVSF code tree. Finally, the simulation result illustrates that the fast-searching achievement of our ROVSF-based scheme.

Keywords

channelization code, code assignment, code re-assignment, OVSF, WCDMA.

I. Introduction

THE rapid growth in the demand for mobile communication leads many research and development efforts towards a new generation of the wireless systems. In the second-generation (2G) CDMA system [1], such as IS-95, users are each assigned a single Orthogonal Constant Spreading Factor (OCSF) [1]. Services provided in existing 2G system are typically limited to voice, facsimile, and low-bit-rate data. To support the high-rate services, multiple OCSF codes are used in [7]. Beyond these 2G services, high-rate services, such as file transfer and QoS-guaranteed multimedia applications, are expected to be supported by the third-generation (3G) systems [3]. To satisfy different requirements, the system has to provide variable data rates. In the 3G wireless standards UMTS/IMT-2000 [6][8][9][10], WCDMA was selected as the kernel technology, for use in the UMTS terrestrial radio access (UTRA) FDD operation by European Telecommunication Standards Institute (ETSI). The WCDMA can flexibly support mixed- and variable- rate services. For WCDMA, spread spectrum is used to transmit multiple channels over a common bandwidth, and the capacity of the WCDMA system is limited by the interference from other channels. Hence, in the 3G technical specification [9], OVSF codes are usually selected to be the channelization codes which are used for spreading.

The OVSF codes is normally represented as a code tree, namely OVSF code-tree, which is formally defined in [4][11]. The data rates is always a power of two with respect to the lowest-date-rate codes. Two important addressed issues on such environment are the *code assignment* problem and *code reassignment* problem [12]. The code-assignment addresses how to place a new call in the code tree to avoid the tree with too many fragment code; it may have significant impact on the code utilization of the system. The code-reassignment addresses how to relocate codes when a new call arrives finding no proper place to accommodate it. This can reduce call blocking, but it will incur code reassignment costs.

Many existing results are divided into OVSF-based and OVSF-like-based schemes, which are discussed as follows. The OVSF-based schemes [12][13][15][16][17] [18] have been heavily investigated. Tseng *et al.* [12][13] proposed single-OVSF code [12] and two-OVSF code [13] assignment/re-assignment schemes in the WCDMA system. The single-code reassignment algorithm is simple, but it possibly incurs many fragmental codes to have code-blocking problem. Although two-OVSF code assignment/re-assignment scheme reduces the code-blocking problem by using the code-movement operation to enlarge the code-capacity. Unfortunately, the code-movement operation heavily incurs the high system complexity. Recently, Minn and Siu [16] developed a dynamic assignment of OVSF codes WCDMA to provide an optimal dynamic code assignment (DCA) scheme, which assigns the

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codes with minimum cost. But the DCA scheme has the slower reaction time because of the transmitter and the receiver must reconnect after a connecter allocating a spreading code. Observe that, the rate information must be transmitted by using the extra bandwidth. Moreover, Liao [17] investigated the effect of OVSF code assignment on PAR (Peak-to-Average Ratio). The assignment method is presented for the purpose of reducing PAR based on the concept of even distribution. Cheng and Lin [18] proposed a OVSF code channel assignment for IMT-2000, and its objection is to provide a multi-rate service using multi-code transmission with less complexity. Finally, Chen *et al*. [15] proposed an implementation of an efficient channelization code assignment to offer an efficient BLRU (Best-fit least Recently Used) code assignment algorithm with less fragmentation. One of main property of the OVSF-based scheme is that if any code of the OVSF code-tree is used, then all of its descendant codes of the OVSF code-tree cannot be used. A high code-blocking rate will be easily generated if using the OVSF-based scheme.

It is worth to develop an OVSF-like scheme, which aims to reduce the code-blocking rate without the code-movement operation. Under an OVSF-like scheme, if a code of the new code-tree is used, then the descendant codes of the new code-tree can be possibly used. The motivation of existing OVSF-like scheme is to reduce the code-blocking rate. The OVSF-like-based result [14] is also developed recently, which aims to develop code assignment/reassignment on the non-conventional OVSF code tree. Tsaur *et al*. [14] developed the symbol rate adoption and blind rate detection using FOSSIL (Forest for OVSF-Sequence-Set-Inducing Lineage). The rate information has been imply between some codes without occupying extra bandwidth. A complete new code-tree is developed, which tries to provide code sequences with different lengths for different users who communicates at different constant symbol rates. Unfortunately, the FOSSIL code-based scheme can dynamically adjust the spreading factor, but greatly loses its efficiency because that the total of available FOSSIL codes are less than that of OVSF codes

This work aims to develop a new channelization code scheme, namely ROVSF (Rotated-Orthogonal Variable Spreading Factor) as illustrated in Fig. 1, is developed to quickly seeking available codes, compared to using the conventional OVSF (Orthogonal Variable Spreading Factor) in the WCDMA system. When new call enters the system, the OVSF-based scheme always takes lots of time to search for a feasible code. Our ROVSF-based scheme provides a fast code assignment strategy based on new proposed code tree structure. Observe that, our ROVSF scheme offers the same code capability with the OVSF-based schemes, and with most of the properties of OVSF code tree. Finally, the simulation result illustrates that the fast-searching achievement of our ROVSF-based scheme.

The rest of this paper is organized as follows. Section 2 presents the basic ideas and challenge of the ROVSF scheme. Our ROVSF code assignment algorithms are presented in section 3. Section 4 illustrates the simulation results. Finally, section 5 concludes this paper.

II. Basic Idea and Challenges

In a WCDMA system [3], two operations, channelization and scrambling operations, are normally applied. The data symbols are spreaded in channelization operation and the scrambled in scrambling operation [3] as illustrated in Fig. 2. The channelization operation mainly transforms every data symbol into a number of chips for the purpose of increasing the bandwidth of data symbols. The number of chips per data symbol is represented as the spreading factor or SF. The greater number of chips per data symbol is, the higher data rate will be. Observe that, channelization codes in WCDMA system are normally adopted the *Orthogonal variable Spreading Factor (*OVSF) codes [12][13][15][16][17] [18] to identify the down/up-link channels. Both the down-link and up-link in a WCDMA apply OVSF codes to match the request data rate.

Before describing our new OVSF-like code tree structure, we initially review the OVSF code tree structure as follows. The OVSF codes [12][13][15][16][17] [18] are arranged in a tree structure for code allocation purposes. The allocation rule of the OVSF code tree can be shown in Fig. 3 (a). The code at the k-th layer spawns two descendant codes, (C, C) and $\left(C, \overline{C}\right)$, if code (C) at the $(k-1)$-th layer of a OVSF code tree as shown in Fig. 3 (a), where $\overline{C}$ is the complement of C. The height of OVSF code tree is

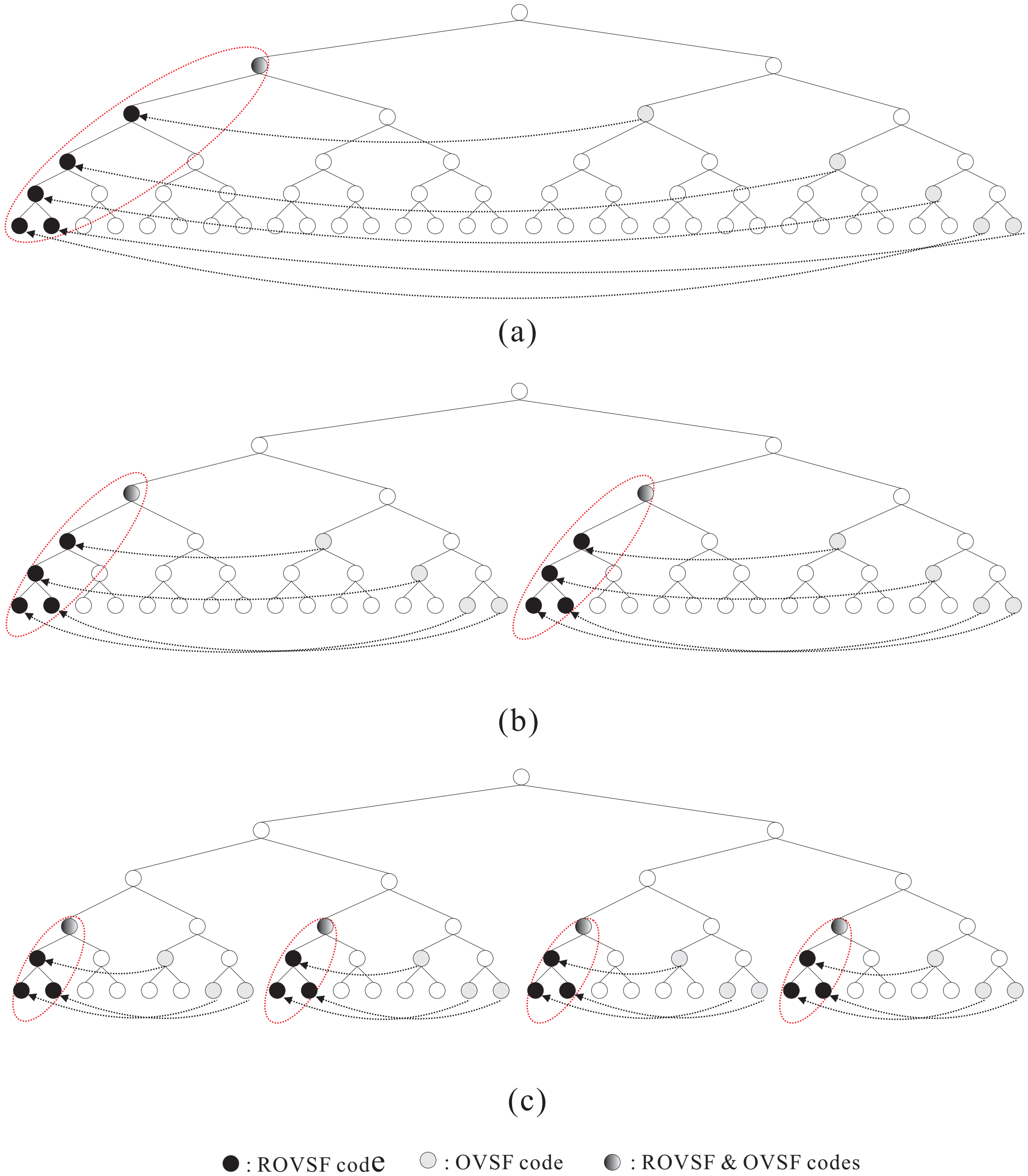


Fig. 1. Our ROVSF code tree

depended on the value of the maximum spreading factor Max_SF. This paper assumes that the $Max\_SF = 256$. Each OVSF code is denoted as $C_{SF,K}$, where SF is the spreading factor and k is the index number, $1 \leq k \leq SF$. For example as illustrated in Fig. 3 (b), consider that root code is $C_{1,1} = (1)$ and the code at the second level are $C_{2,1} = (1, 1)$ and $C_{2,2} = (1, -1)$. Observe that $C_{2,1}$ and $C_{2,1}$ are said as a brother-code pair. The total number of OVSF codes at k-th layer is also equal to $SF = 2^k$, where root of OVSF code tree is assumed at 0-th layer. Consequently, a short OVSF code, near the root of OVSF code tree, offers a higher data rate and a long OVSF code, near the leaf of OVSF code tree, offers a lower data rate. Some important properties of OVSF code tree are reviewed [12][13][15][16][17] [18].

- Each pair of OVSF codes (brother-code pair) at the same k-th layer are orthogonal.
- Each pair of OVSF codes α and β at different layers are orthogonal if α and β without the ancestor-descendant relationship.
- Each code in the leaf node of the OVSF code tree has the minimal data rate R.
- In a OVSF code tree, if the data rate is R' for any OVSF code at k-th layer, then the data rate is $2R'$ for any OVSF code at

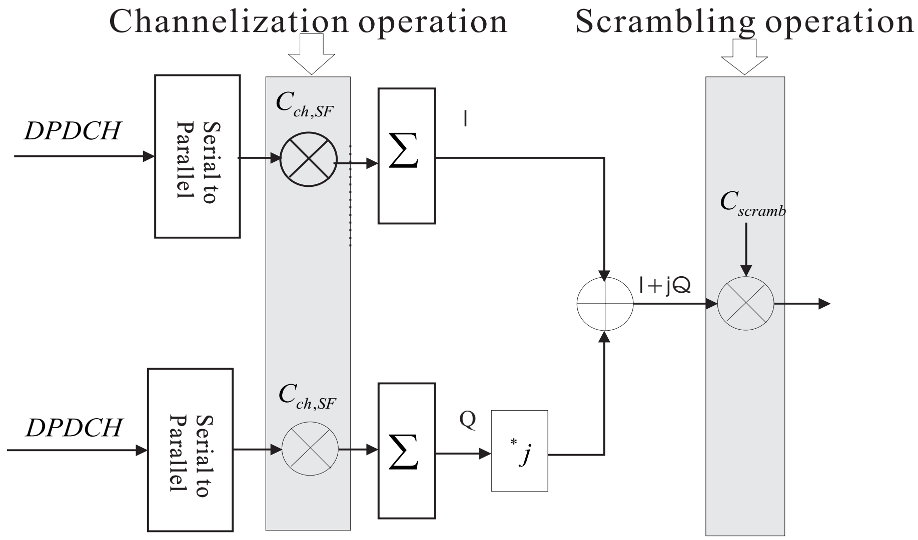


Fig. 2. The channelization and scrambling operations of the multi-code transmission system

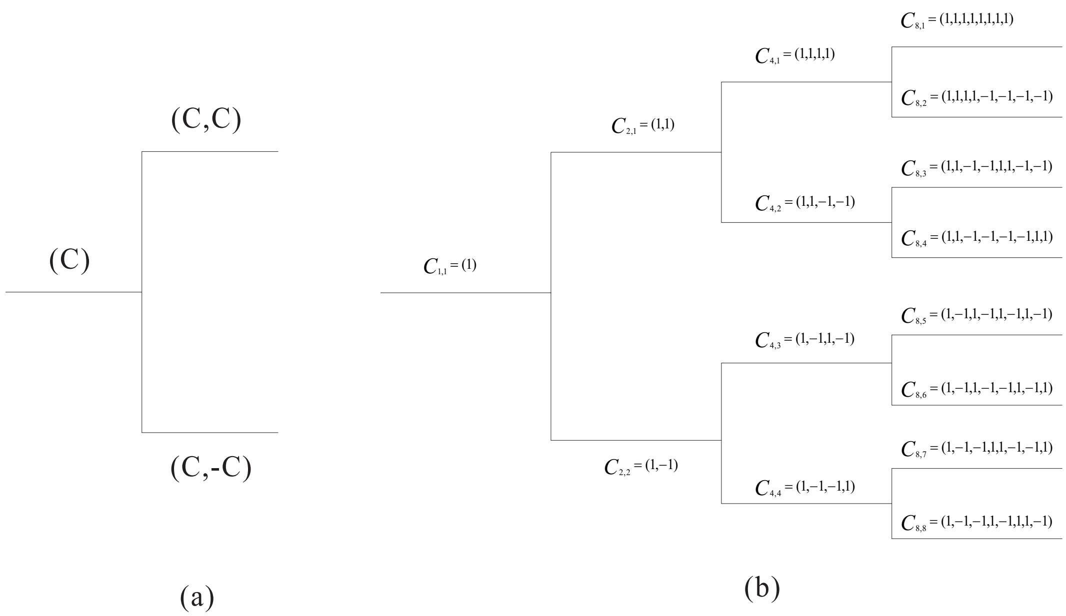


Fig. 3. The OVSF code tree structure

$(k-1)$-th layer.

The ”transmission unit” that can be assigned to a user is codes. Two users should not be given two codes that are not orthogonal. When a new call arrives requesting for a code of rate kR, where k is power of 2, we have to allocate a free code of rate kR for it. The **code assignment problem** is to address the allocation policy when multiple such free codes exist in the code tree. When no such free code exits but the code tree has enough free capacity ($> kR$), two solutions have. The first one is reject this call, for which called as *code blocking*. A bad assignment may cause deficiency in the future. The second is to relocate some codes in the code tree to ”squeeze” a free space for the new call. This is called the **code re-assignment problem**. These two problems are very similar to traditional memory management problems in the Operating System. A dynamic code assignment algorithm is proposed in [16] to determine the sub-tree that can be vacated with the minimum cost. A code assignment and re-assignment strategies are developed in [12] to address where to place those codes being relocated. Generally, the code re-assignment incurs lots of extra system efforts by moving an assigned code from a sub-tree to another sub-tree.

This work mainly defines a new OVSF-like code tree with the code-locality capability to provide a fast searching code scheme. This article only considers the code assignment in the new OVSF-like code tree. Several definitions and properties of our proposed ROVSF are defined. In this work, the ROVSF code is denoted as $RC_{SF,K}$, and the $RC_{SF,K}$ recursively constructs a ROVSF code binary-tree structure. The code $RC_{SF,K}$ are denoted as a ROVSF code if any ROVSF code $RC_{X,Y}$ is orthogonal to its two children code $RC_{2X,2Y-1}$ and $RC_{2X,2Y}$.

Definition 1: **ROVSF code tree:** *The ROVSF code of root node of ROVSF code tree is assumed as 1, and two children codes of the root node are initially set to be $(-1,-1)$ and $(-1,1)$, respectively. Consider a neighboring ROVSF codes $RC_{i,j} = (A)$ and $RC_{i,j-1=}\,(B)$ at k-th level, $i = 2^k$, of code tree, where A and B denote as the ROVSF codes of $RC_{i,j}$ and $RC_{i,j-1}$, respectively. Two children codes of $RC_{i,j}$ at $(k+1)$-th level of ROVSF code tree are $RC_{2i,2j-1} = (-B,-B)$ and $RC_{2i,2j} = (B,-B)$. Similarly, two children codes of $RC_{i,j-1}$ are $RC_{2i,2j-2} = (-A,-A)$ and $RC_{2i,2j-3} = (A,-A)$. Two codes (P,Q) and (R,S) are said as brother codes if $Q = S$ and P is the complement of R, i.e., $P = -R$. The constructing rule is shown in Fig. 5(a).*

For example as shown in Fig. 5(b), let the root code of ROVSF tree be $RC_{1,1} = (1)$, and two children codes at the second level are $RC_{2,1} = (-1,-1)$ and $RC_{2,2} = (-1,1)$ as illustrated in Fig. 5(b). Therefore, $RC_{4,1} = (1,-1,1,-1)$, $RC_{4,2} = (-1,1,1,-1)$, $RC_{4,3} = (1,1,1,1)$, and $RC_{4,4} = (-1,-1,1,1)$.

In this study, code $RC_{i,n}$ is an ancestor of $RC_{j,m}$ (or, $RC_{j,m}$ is a descendant of $RC_{i,n}$) if the node representing $RC_{i,n}$ in the ROVSF code tree is an ancestor of the node representing $RC_{j,m}$. Given a ROVSF code $RC_{i,j}$, let a $RC_{i,j}$ be partitioned into m equal-sized sub-codes, and let ${}^{n}_{m}RC_{k,i}$ be denoted as the n-th sub-code. For example, if $RC_{4,1} = (1,-1,1,-1)$, then ${}^{1}_{2}RC_{4,1} = (1,-1)$ and ${}^{2}_{2}RC_{4,1} = (1,-1)$. Codes $RC_{i,n}$ and $RC_{j,m}$ are cyclic orthogonal with the unit cyclic length l equal to $GCD(i,j)$. For instance as shown in 5(b), two ROVSF codes $RC_{2,1}$ and $RC_{4,2}$ are cyclic orthogonal, so $RC_{2,1} \cdot {}^{1}_{\frac{4}{GCD(2,4)}=2} RC_{4,1}$ $= (-1,-1)\cdot(1,-1) = 0$ and $RC_{2,1} \cdot {}^{2}_{2}\, RC_{4,1} = (-1,-1)\cdot(1,-1) = 0$, where the unit cyclic length $l = GCD(2,4) = 2$.

Some important properties of our ROVSF code tree are discussed as follows.

Property 1. *The maximum data rate in a n-layer ROVSF tree is $2^{n-1}R$.*

Property 2. *Two ROVSF codes $RC_{i,j}$ and $RC_{i,j'}$ at k*-th level, $i = 2^k$, *of the ROVSF code tree are orthogonal.*

For example as shown in Fig. 5(b), the code length of $RC_{2,1}$, $RC_{2,2}$, $RC_{2,3}$, and $RC_{2,4}$ is equal to 2^2. Each pair of two codes from $RC_{4,1} = (1,-1,1,-1)$, $RC_{4,2} = (-1,1,1,-1)$, $RC_{4,3} = (1,1,1,1)$ and $RC_{4,4} = (-1,-1,1,1)$ are orthogonal.

Lemma 1. *A ROVSF code $RC_{i,j}$ is cyclic orthogonal to its two children codes $RC_{2i,2j}$ and $RC_{2i,2j-1}$.*

proof: Based on definition 1, we assume that a ROVSF code $RC_{i,j}$ is (A,B) where i and j are any integer, thus its brother code is $RC_{i,j-1} = (-A,B)$, where i is an integer. Then the $RC_{i,j}$'s two children codes are $RC_{2i,2j} = \left(\overline{RC_{i,j-1}}, \overline{RC_{i,j-1}}\right) =$ $(A,-B,A,-B)$ and $RC_{2i,2j-1} = \left(RC_{i,j}, \overline{RC_{i,j}}\right) = (-A,B,A,-B)$. Consequently, we have the results of $RC_{i,j} \cdot {}^{1}_{\frac{2i}{GCD(i,2i)}=2}RC_{2i,2j} =$ $(A,B)\cdot(A,-B) = 1-1 = 0$, $RC_{i,j} \cdot {}^{2}_{2}RC_{2i,2j} = (A,B)\cdot(A,-B) = 1-1 = 0$. Observe that ${}^{2}_{2}RC_{2i,2j}$ is equal to ${}^{2}_{2}RC_{2i,2j-1}$ and ${}^{1}_{2}RC_{2i,2j}$ is the complement of ${}^{1}_{2}RC_{2i,2j-1}$, therefore, $RC_{i,j} \cdot {}^{1}_{2}RC_{2i,2j-1} = (A,B)\cdot(-A,B) = -1+1 = 0$ and $RC_{i,j} \cdot {}^{2}_{2}RC_{2i,2j-1} = (A,B)\cdot(A,-B) = 1-1 = 0$.

For example as illustrated in Fig. 5(b), $RC_{2,1} = (-1,-1)$ is cyclic orthogonal to $RC_{4,1} = (1,-1,1,-1)$ and $RC_{4,2} = (-1,1,1,-1)$.

Lemma 2. *A ROVSF code $RC_{i,j}$ is cyclic orthogonal to any descendant code of $RC_{i,j}$.*

proof: By the linear algebra [2], if a vector V is orthogonal to a vector V' and the vector V' is orthogonal a vector V'', then the vector V is orthogonal to the vector V''. This indicates that the transitive property exists for the orthogonal relation. This transitive property is also applied to the cyclic orthogonal. Based on Lemma 1, $RC_{i,j}$ is cyclic orthogonal to its two children codes $RC_{2i,2j}$ and $RC_{2i,2j-1}$. Continually, $RC_{2i,2j}$ and $RC_{2i,2j-1}$ are cyclic orthogonal to their children codes, respectively. Based on the transitive property, $RC_{i,j}$ is cyclic orthogonal to children codes of $RC_{2i,2j}$ and $RC_{2i,2j-1}$. Further, $RC_{i,j}$ is cyclic orthogonal to

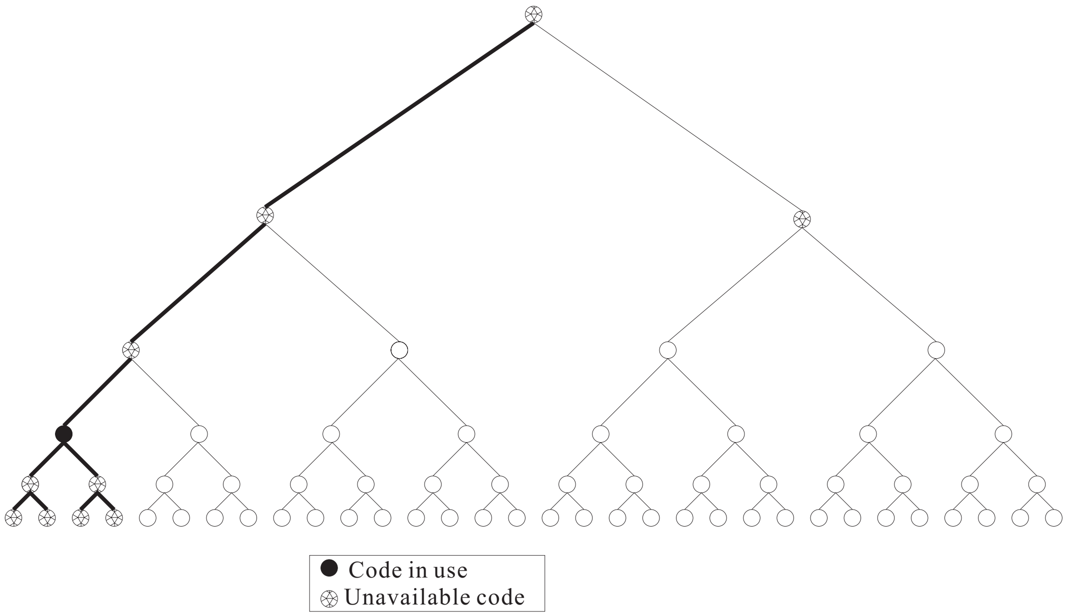


Fig. 4. Assigned and unavailable codes in OVSF code tree

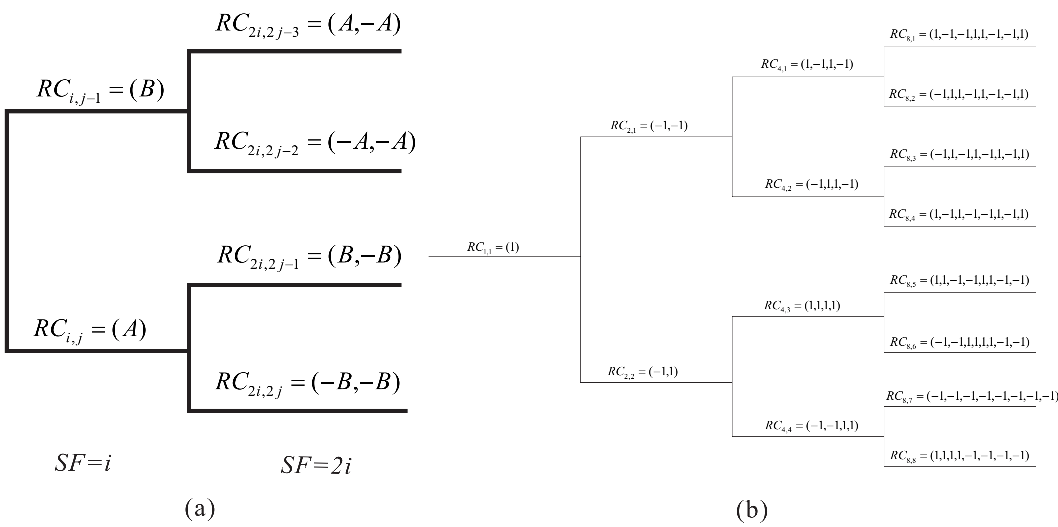


Fig. 5. The ROVSF code tree structure

any descendant code of $RC_{i,j}$.

Lemma 3. *Given a pair of brother codes $RC_{i,j} = (A, B)$ and $RC_{i,j-1} = (-A, B)$, $RC_{i,j}$ (or, $RC_{i,j-1}$) is not cyclic orthogonal to any descendant code of $RC_{i,j-1}$ (or, $RC_{i,j}$).*

Proof: We show that $RC_{i,j} = (A, B)$ is not cyclic orthogonal to children codes $RC_{2i,2j} = (-A, -B, -A, -B)$ and $RC_{2i,2j-1} = (A, B, -A, -B)$ of $RC_{i,j-1}$. This is because that $RC_{i,j} \cdot_2 RC_{2i,2j} = (A, B) \cdot (-A, -B) = -1 - 1 \neq 0$ and $RC_{i,j} \cdot_2 RC_{2i,2j-1} = (A, B) \cdot (A, B) = 1 + 1 \neq 0$. Based on Lemma 2, $RC_{i,j}$ is not cyclic orthogonal to children codes of $RC_{i,j-1}$ and children codes of $RC_{i,j-1}$ are cyclic orthogonal to all descendant codes of children codes of $RC_{i,j-1}$. Therefore, $RC_{i,j}$ (or, $RC_{i,j-1}$) is not cyclic orthogonal to any descendant code of $RC_{i,j-1}$ (or, $RC_{i,j}$).

Let $RC_{\alpha,\beta}$ be an ancestor code of $RC_{i,j}$ and $RC_{i,j-1}$. Then, both of $RC_{i,j}$ and $RC_{i,j-1}$ are not cyclic orthogonal to brother code of $RC_{\alpha,\beta}$.

For the OVSF code assignment scheme, a highly-cost tree traversal operation is performed to search for an available code in the

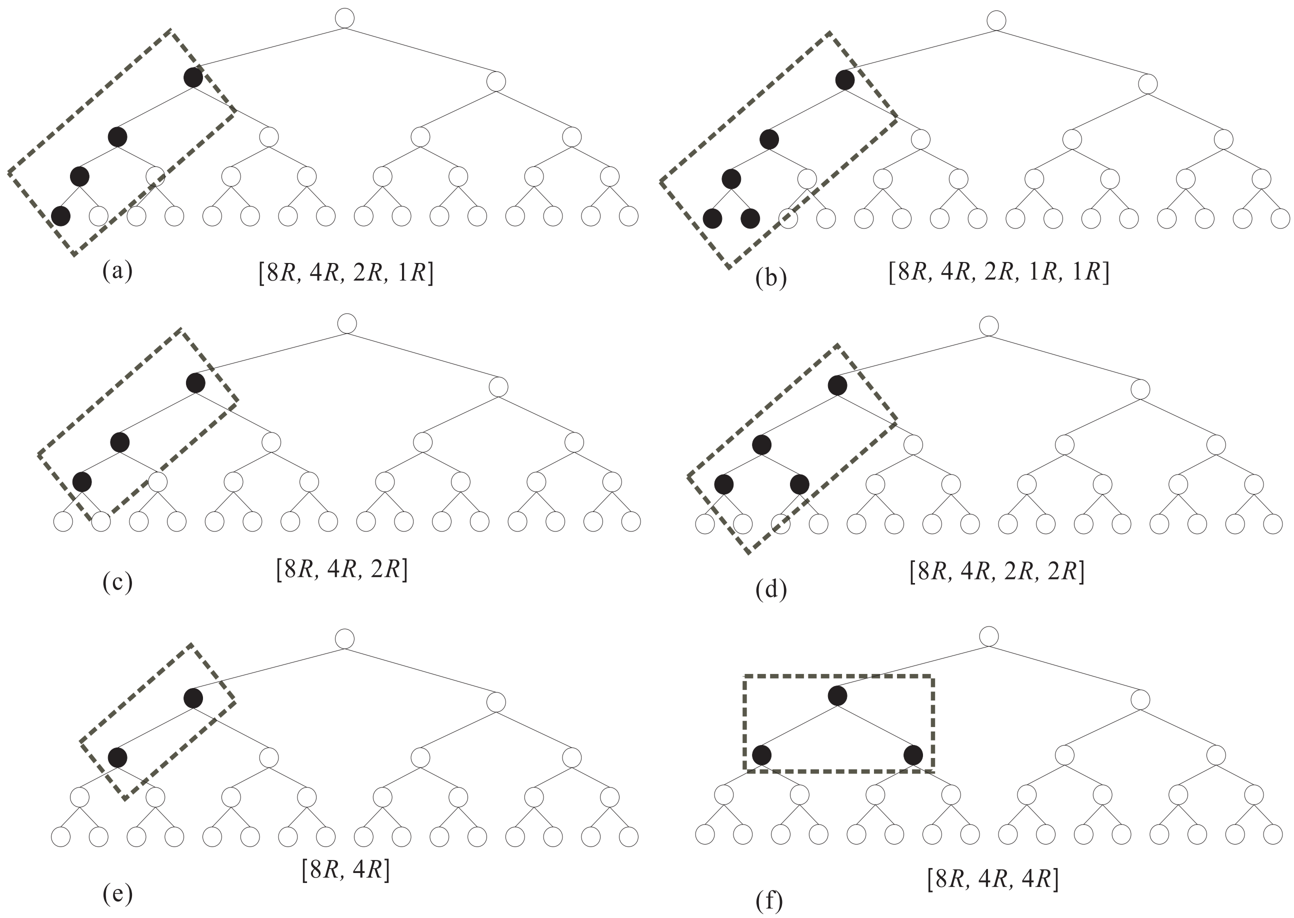


Fig. 6. Examples for the linear-code chains

OVSF code tree according to the OVSF code-tree management scheme. In the worse case, it is possible to traverse all nodes of the OVSF code tree to search for the feasible code in the code tree. The ROVSF code assignment scheme offers a simple searching mechanism in order to reduce the cost of searching for a feasible code in the ROVSF code tree. The key difference of OVSF and ROVSF code trees is illustrated in Fig. 1. Observe that, every node of a OVSF code tree are mapping to the corresponding node of a ROVSF code tree as shown in Fig. 1(a). These mapping nodes can forms a path, which is denoted as a *linear-code chain.* Observe that, there may exist one or more linear-code chains for a ROVSF code tree. The main idea of our ROVSF code assignment scheme is to assign request data-rate codes to the *linear-code chain*. The formal definition of *linear-code chain* is defined.

Definition 2: **Linear-Code Chain:** *Given a data rate* $R_{\max} = 2^{\log_2 R_{\max}}$ (*or called as chain-max-code*), *we denote* S *as a linear-code chain as follows.*

1) Let linear-code chain S *be a subset of* $S_k = [R_{\max}, \frac{R_{\max}}{2^1}, \frac{R_{\max}}{2^2}, \frac{R_{\max}}{2^3}, \cdots, , \frac{R_{\max}}{2^k}]$, *where* $0 \le k \le$ *log*$_2$*(*$R_{\max}$*),*

or

2) Let linear-code chain $S = S_k \cup \{\frac{R_{\max}}{2^k}\} = [R_{\max}, \frac{R_{\max}}{2^1}, \frac{R_{\max}}{2^2}, \frac{R_{\max}}{2^3}, \cdots, \underbrace{\frac{R_{\max}}{2^k}, \frac{R_{\max}}{2^k}}]$, *where* $\underbrace{\frac{R_{\max}}{2^k}, \frac{R_{\max}}{2^k}}$ *are on the same level of the ROVSF code tree, , where* $0 \le k \le$ *log*$_2$*(*$R_{\max}$*).*

Lemma 4: *Given a linear-code chain with a chain-max-code, where the chain-max-code on the* α*-layer of* n*-layer ROVSF code tree. Thus, the total data rate of the linear-code chain is* $2^{\alpha}R$*.*

Proof: Since the chain-max-code is $2^{\alpha-1}$, so the total data rate of the linear-code chain is

$$2^{\alpha-1} + 2^{\alpha-2} + ... + 2 + 1 + 1 = \left(2^{\alpha-1} + 2^{\alpha-2} + ... + 2 + 1\right) + 1 = 2^{\alpha}.$$

Consider a 5-layer ROVSF code tree as shown in Fig. 6. For case 1 of definition 2, linear-code chains $[8R, 4R, 2R, 1R]$,

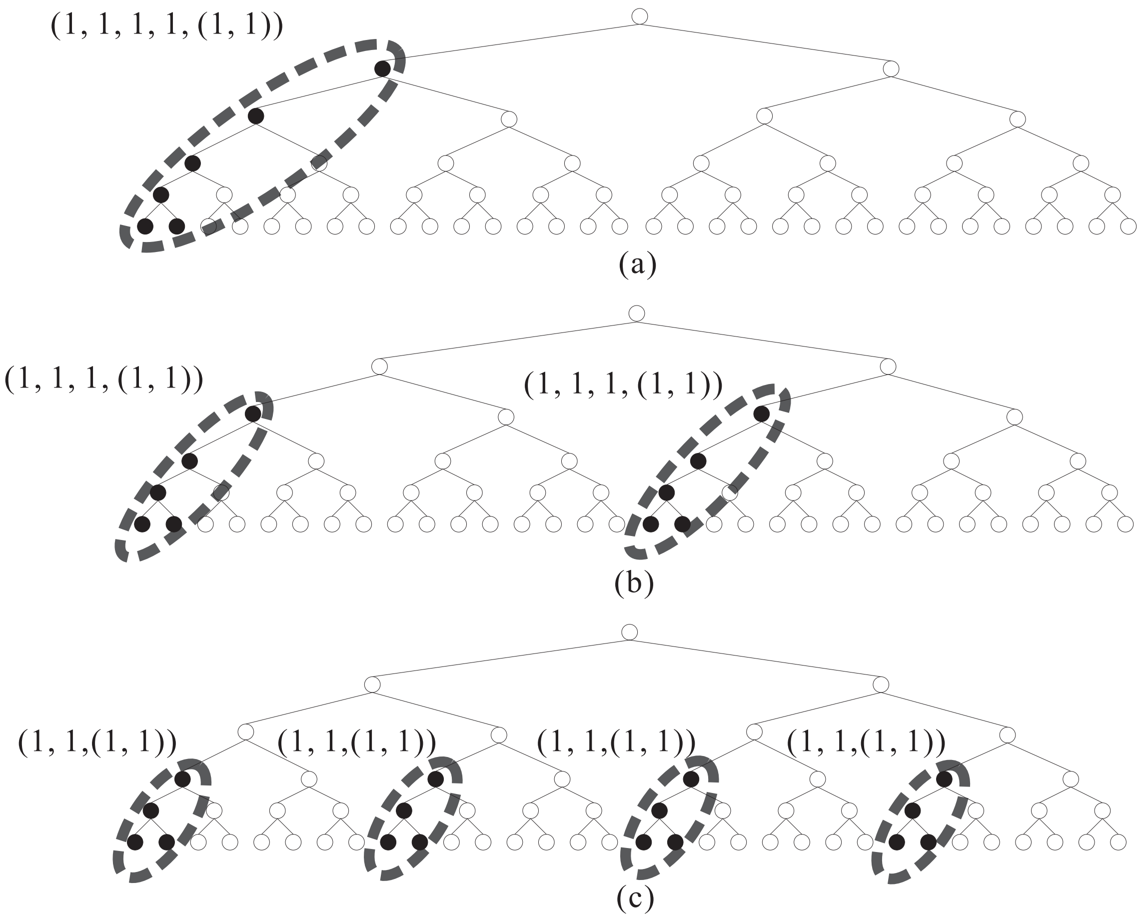


Fig. 7. Examples of linear-code chains with different length

$[8R, 4R, 2R]$, and $[8R, 4R]$ as illustrated in Figs. 6(a), (c), and (e), respectively. For case 2 of definition 2, linear-code chains $[8R, 4R, 2R, \underbrace{1R, 1R}]$, $[8R, 4R, \underbrace{2R, 2R}]$, and $[8R, \underbrace{4R, 4R}]$ as illustrated in Figs. 6(b), (d), and (f), respectively, where $\underbrace{1R, 1R}$, $\underbrace{2R, 2R}$, and $\underbrace{4R, 4R}$ are respectively on the same level of the ROVSF code tree. For example as shown in Fig. 7, a 6-layer of ROVSF code tree is given. Fig. 7(a) shows that there has one linear-code chain with chain-max-code $16R$. Fig. 7(b) illustrates that there are two linear-code chains with chain-max-code $8R$. Fig. 7(c) displays that four linear-code chains with chain-max-code $4R$ exist.

Further, for case 1 of definition 2, we may use $(k+1)$ bit-word $BW = (b_k, b_{k-1}, b_{k-2}, \cdots, b_1, b_0)$ to represent as the linear-code chain S be a subset of $S_k = [R_{\max}, \frac{R_{\max}}{2^1}, \frac{R_{\max}}{2^2}, \frac{R_{\max}}{2^3}, \cdots, \frac{R_{\max}}{2^k}]$, where $k = \log_2(\max)$. If $b_i = 1$ indicates that $\frac{R_{\max}}{2^{k-i}}$ exists, and if $b_i = 0$ indicates that $\frac{R_{\max}}{2^{k-i}}$ does not exist, where $0 \le i \le k$. For example as shown in Fig. 6(a), a linear-code chain with bit-word $(1, 1, 1, 1)$ exists. For case 2 of definition 2, we also denote $(k+2)$ bit-word $BW = (b_k, b_{k-1}, b_{k-2}, \cdots, (b_j, b_j), 0, \cdots, 0)$, where $0 \le j \le k$, as the linear-code chain S be a subset of $S_k = [R_{\max}, \frac{R_{\max}}{2^1}, \frac{R_{\max}}{2^2}, \frac{R_{\max}}{2^3}, \cdots, \underbrace{\frac{R_{\max}}{2^j}, \frac{R_{\max}}{2^j}}]$, if $b_i = 1$ indicates that $\frac{R_{\max}}{2^{k-i}}$ exists, and if $b_i = 0$ indicates that $\frac{R_{\max}}{2^i}$ does not exist, where $1 \le i \le k+1$. For example, the bit-words of $[8R, 4R, 2R, 1R]$ and $[8R, 4R, 2R, 1R, 1R]$ are $(1, 1, 1, 1)$ and $(1, 1, 1, (1, 1))$, respectively, and $[8R, 4R]$ and the bit-words of $[8R, 4R, 4R]$ are $(1, 1, 0, 0)$ and $(1, (1, 1), 0, 0)$, respectively.

Each linear-code chain has its own bit-word BW. Consider that a n-layer ROVSF code tree, there exist $2^{n-\alpha-1}$ same linear-code chains with a chain-max-code $R_{\max} = 2^{\alpha-1}$, where the chain-max-code on the α-layer of n-layer ROVSF code tree. Therefore, there are $2^{n-\alpha-1}$ bit-words BWs. We use a bit-word sequence $[BW_1, BW_2, \cdots, BW_{2^{n-\alpha-1}}]$ to record all of the code-assignment

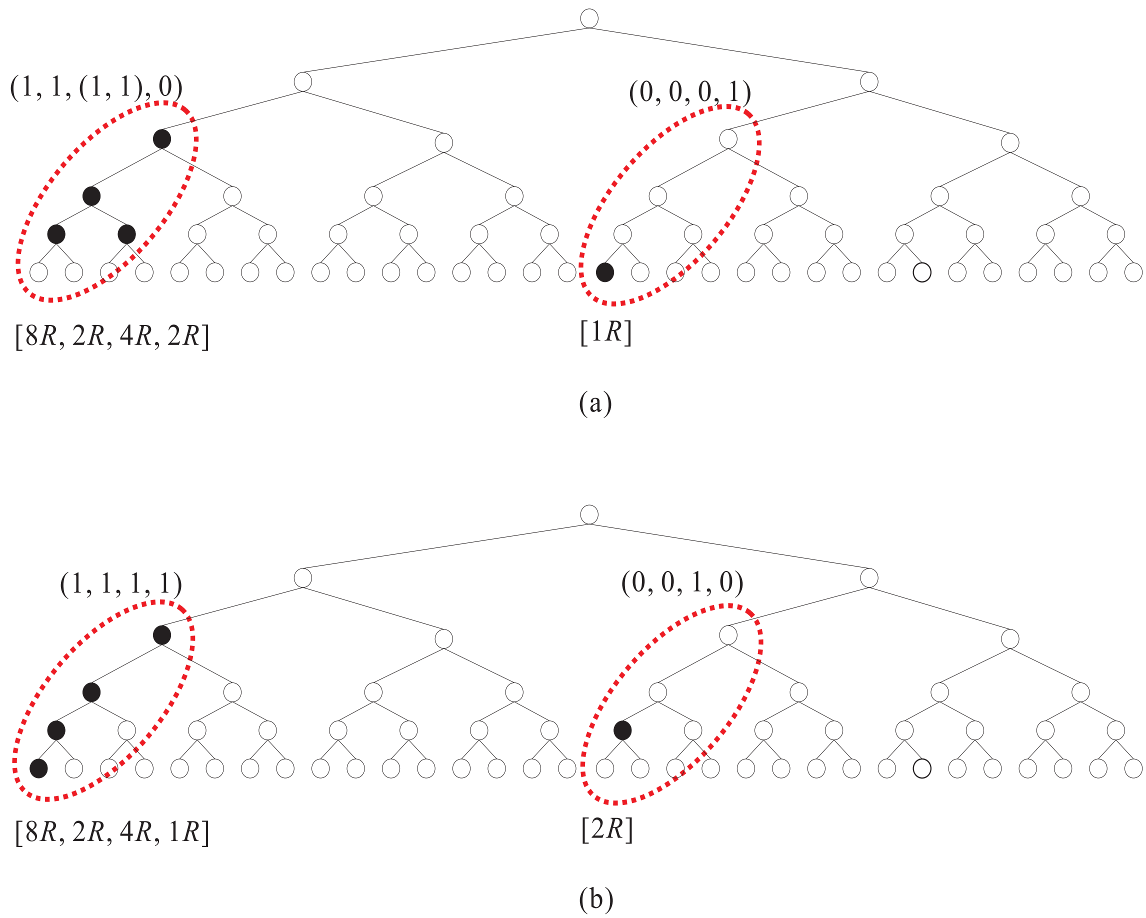


Fig. 8. Example of LCC assignment phase

status. For example as shown in Fig. 7(a), a bit-word sequence $[(1, 1, 1, 1, (1, 1))]$ exists. Fig. 7(b) shows a bit-word sequence $[(1, 1, 1, (1, 1)), (1, 1, 1, (1, 1))]$, and Fig. 7(c) shows a bit-word sequence $[(1, 1, (1, 1)), (1, 1, (1, 1)), (1, 1, (1, 1)), (1, 1, (1, 1))]$.

III. The Fast ROVSF-Code Assignment Scheme

In the following, we present our ROVSF code assignment scheme, which is divided into two phases, Linear-Code Chain (LCC) assignment (LCC), Non-linear-Code Chain (NCC) assignment phases. In addition, a dynamic adjustment operation of linear-code chain is introduced in the LCC phase to dynamically adjust the length of the linear-code chain, which aims to reduce the rate-blocking problem.

Initially, we will search a feasible data rate code by LCC assignment scheme and then apply the NCC assignment scheme. The detail operations are presented as follows.

A. *Linear-Code Chain (LCC) Assignment Phase*

Consider that a n-layer ROVSF code tree, there exist $2^{n-\alpha-1}$ linear-code chains, where a chain-max-code $R_{\max} = 2^{\alpha-1}$. The LCC assignment phase aims to assign an incoming data rate XR to one of $2^{n-\alpha-1}$ linear-code chains. This work is achieved by checking from the bit-word sequence $[BW_1, BW_2, \cdots, BW_{2^{n-\alpha-1}}]$. The LCC scheme offers a checking function to check if an incoming data rate XR can assigned to i-th linear-code chain or not. Using the left-most strategy, we initially try to assign incoming data rate XR to BW_1. If it is failed, we continually attempt to assign XR to BW_2. Repeatedly executing above operation until XR can assign to BW_j, where $j \leq 2^{n-\alpha-1}$. If it still can not assign XR to $BW_{2^{n-\alpha-1}}$, then we perform the NCC phase, which will be described later.

We describe how to try to assign XR to $BW = (b_k, b_{k-1}, b_{k-2}, \cdots, b_1, b_0)$, where $b_i = 1, 0$, or $(1,1)$, and $0 \le i \le k$. Let $\beta = \log_2 X$, we have the following assignment rules.

A1: If there exists $(b_k, b_{k-1}, b_{k-2}, \cdots, (b_j, b_j), 0, \cdots, 0)$ and $\beta < j$ then the assignment is failed even if $b_\beta = 0$. For instance as shown in Fig. 8(a), data rate $1R$ cannot be assigned to linear-code chain $[8R, 2R, 4R, 2R]$, where bit-word is $(1, 1, (1, 1), 0)$.

A2: If $b_\beta = 1$ and there is $b_\gamma = 1$ and $r < \beta$, then the assignment is failed. For instance as shown in Fig. 8(b), data rate $2R$ cannot be assigned to linear-code chain $[8R, 1R, 4R, 2R]$, where bit-word is $(1, 1, 1, 1)$.

A3: If $b_\beta = 1$ but there is no $b_\gamma = 1$, where $r < \beta$, then the we can assign XR to let the linear-code chain to be $(b_k, b_{k-1}, b_{k-2}, \cdots, (b_j, b_j), 0, \cdots$ For instance, $2R$ can assign to linear-code chain $[8R, 4R, 2R]$ with bit-word $(1, 1, 1, 0)$ to be $[8R, 4R, 2R, 2R]$ with bit-word $(1, 1, (1, 1), 0)$.

Consider that a n-layer ROVSF code tree, there exist $2^{n-\alpha-1}$ linear-code chains, where a chain-max-code $R_{\max} = 2^{\alpha-1}$. Given an incoming data rate XR, where $\beta = \log_2 X$, we give the formal algorithm of Linear-Code Chain (LCC) assignment as follows.

Step 1: Repeatedly perform to assign incoming data rate XR to i-th linear-code chain with bit-word BW_i until one is successful, where $1 \le i \le 2^{n-\alpha-1}$.

Step 2: If incoming data rate XR cannot be assigned to last linear-code chain with bit-word $BW_{2^{n-\alpha-1}}$, then enters the NCC assignment phase.

For example, the LCC assignment operation is shown in Fig. 9(a)˜(c), $[8R, 4R, 1R]$ are successful assigned into first linear-code chain with bit-word $(1, 1, 0, 1)$. Then, $[8R]$ is assigned into second linear-code chain with bit-word $(1, 0, 0, 0)$ as shown in Fig. 9(d). This completes the LCC operations. The third incoming $8R$ executes the NCC operation.

B. Non-linear-Code Chain (NCC) Assignment Phase

The purpose of NCC assignment phase is to assign new incoming data rate YR. Observe that YR is failed to assign to all linear-code chains in the LCC assignment phase. The YR is attempted to assign into the ROVSF code tree as follows. The LCC assignment try to assign YR to OVSF code tree, we have the following assignment rules, where $\gamma = \log_2 Y$.

- If there exists linear-code chain $(b_k = 1, 0, 0, 0, \cdots, 0)$ and $\gamma = k$ then we may assign YR to neighboring node of node N of linear-code chain on the same level of ROVSF code tree, where date rate of node N is 2^k. For instance as shown in Fig. 10(a), $8R$ is assigned to neighboring code on the second linear-code chains.
- If there exists $(0, 0, \cdots, 0, (b_j, b_j), 0, \cdots, 0)$ and $\gamma = j$ then we may assign YR to neighboring node of node N of linear-code chain on the same level of ROVSF code tree, where date rate of node N is 2^j. For instance as shown in Fig. 10(b), $4R$ is assigned to neighboring code of first linear-code chain with bit-word $(0, (1, 1), 0, 0)$.

We give the formal algorithm of Non-linear-Code Chain (NCC) assignment operation as follows.

Step 1: Repeatedly assign incoming data rate YR to neighboring codes of i-th linear-code chain until one is successful, where $1 \le i \le 2^{n-\alpha-1}$.

Step 2: If data rate YR cannot be assigned to neighboring codes of any linear-code chain, then there having a rate blocking.

For example as shown in Fig. 10(a), $8R$ cannot be assigned into the first linear-code chain, but can be assigned into the second linear-code chain.

C. Dynamic Adjustment Operation of Linear-Code Chain

A dynamic adjustment operation of linear-code chain is introduced in the LCC phase for the purpose of dynamically changing the length of the linear-code chain. This operation aims to possibly improve the rate-blocking. By using the dynamic adjustment scheme, no fixed length of linear-code chain is required. We add one new rule of assigning XR to $BW = (b_k, b_{k-1}, b_{k-2}, \cdots, b_1, b_0)$, where $b_i = 1, 0$, or $(1, 1)$, and $0 \le i \le k$. Let $\beta = \log_2 X$, as follows.

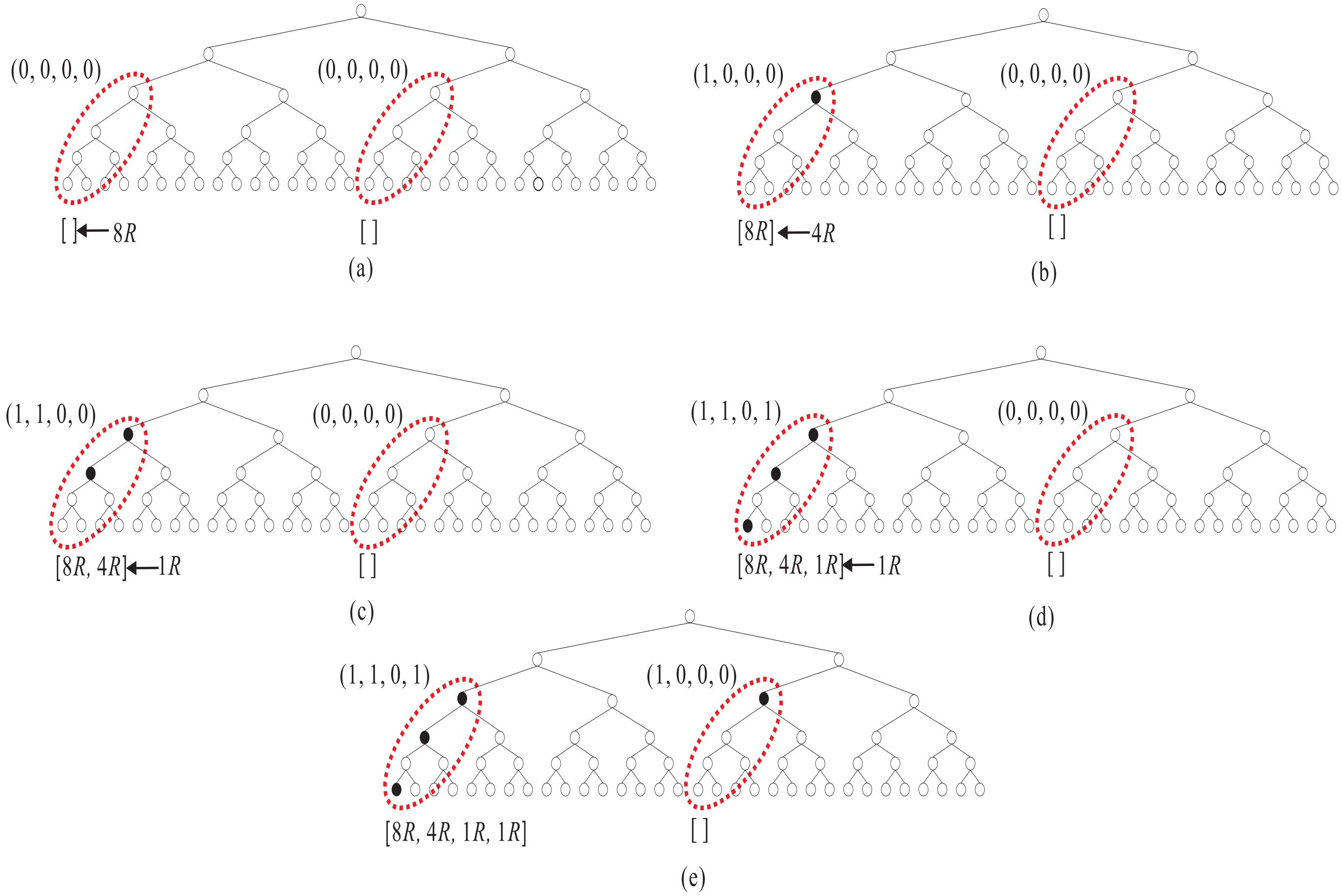


Fig. 9. Example of LCC assignment phase

A1': This step is same as A1 step.

A2': This step is same as A2 step.

A3': This step is same as A3 step.

A4': If there is $(b_k, (b_{k-1}, b_{k-1}), 0, \cdots, 0)$ or $(b_k, b_{k-1}, b_{k-2}, \cdots, b_j,\ 0, \cdots, 0)$, where $b_i = 1$ and $j \leq i \leq k$, if incoming data rate is 2^{k+t}, $1 \leq t \leq n-k$, we may adjust the linear-code chain to be $(b_{k+t}, \cdots, b_k, (b_{k-1}, b_{k-1}), 0, \cdots, 0)$ or $(b_{k+t}, \cdots, b_k, b_{k-1}, b_{k-2}, \cdots, b_j, 0, \cdots, 0)$. For example as shown in Fig. 11, the linear-code chain $[8R, 4R, 4R]$ is adjusted to be $[16R, 8R, 4R, 4R]$.

IV. Performance Analysis

We have developed a simulation program by C++ to evaluate the performance of our proposed ROVSF-based scheme. The simulation program has been designed to simulate the channelization operation in the WCDMA system, which has the following simulation assumptions.

- The maximum SF of our ROVSF code tree is 256.
- Every experiment values are obtained the average values by running 100 rounds.
- Each request date rate is ranging from $1R$ to $16R$, which are randomly generated following the uniform-distribution rule.
- The length of linear-code chain is ranging from 3 to 6.
- The dynamic adjustment operation are setting to be on or off.

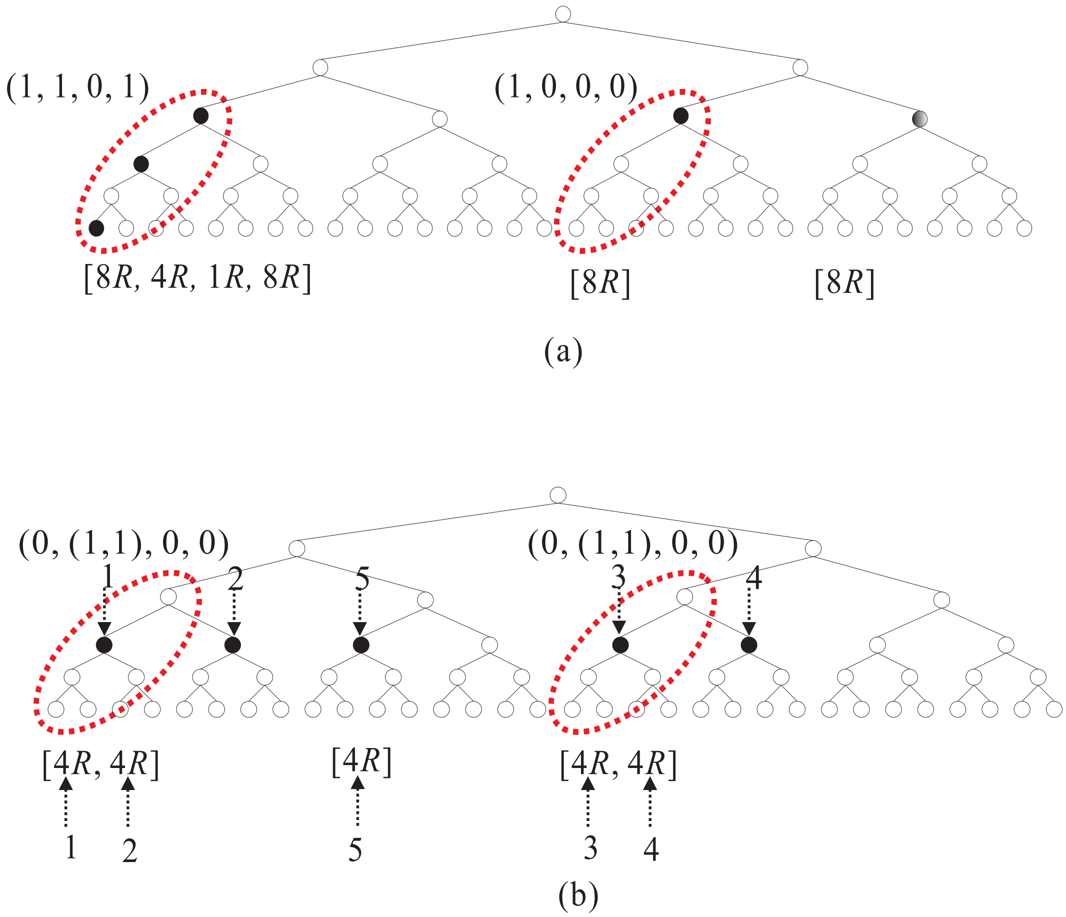


Fig. 10. Example of NCC assignment phase

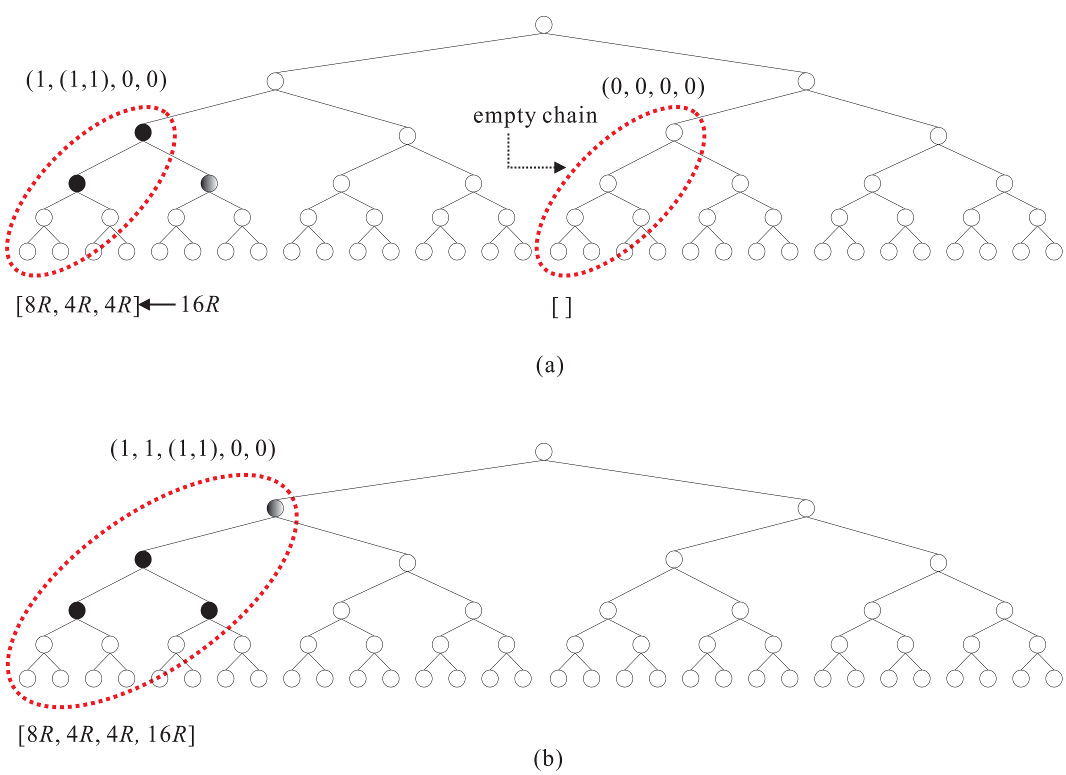
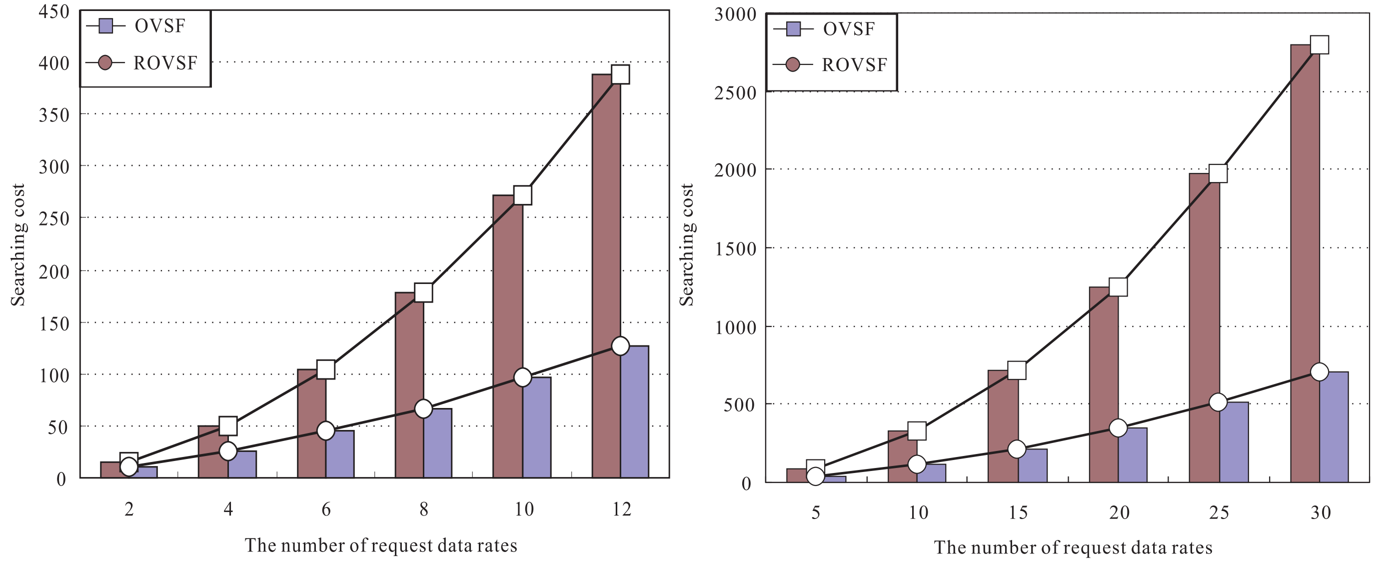


Fig. 11. Example of dynamic adjustment operation



(a) (b)

$SF = 128$	The number of request data rates	2	4	6	8	10	12
	IR	26.67%	50.00%	56.73%	62.92%	64.70%	67.27%
$SF = 256$	The number of request data rates	5	10	15	20	25	30
	IR	53.93%	64.95%	70.06%	72.55%	73.96%	74.73%

(c)

Fig. 12. Performance of searching cost under (a) $Max_S F$ = 128, (b) $Max_S F$=256, and (c) the IR result

When any new call enters the WCDMA system, the system search for an available code. The performance metrics are observed in this work as defined below.

1. *Searching Cost (SC)*: The total searching steps to successfully search for a feasible code in the OVSF and ROVSF code trees.

2. *Blocking Rate (BR)*: The probability of a new incoming request data rate cannot be assigned a feasible code in the OVSF and ROVSF code trees.

It is worth mentioning that our scheme prefers to obtain the low searching cost and low blocking rate. In the following, we illustrate the performance of searching cost and blocking rate as follows.

A. Performance of Searching Cost

The observed results of the performance of searching cost vs. the various number of request data rates are illustrated in Fig. 12. The searching cost is obtained by calculating tree-traversal step until a code-blocking is occurred. The situation of same request data rates are simultaneously applied to OVSF and ROVSF code trees to obtain the their searching cost. The maximum spreading factor of our simulator are $Max\_SF = 128$ or $Max\_SF = 256$ are illustrated in Fig. 12(a) and Fig. 12(b), respectively. Fig. 12(a) shows that the searching cost of ROVSF and OVSF are 25 and 50 if the number of request data rate is 4, and 135 and 380 if the number of request date rate is 12. Fig. 12(b) shows that the searching cost of ROVSF and OVSF are 213 and 710 if the number of request data rate is 15, and 645 and 2745 if the number of request date rate is 30. Averagely, the searching cost of ROVSF-based

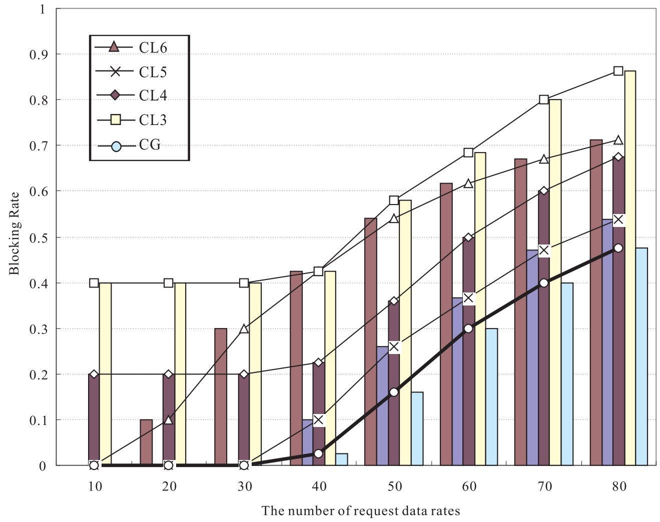


Fig. 13. The performance of blocking rate

scheme is about less 50% than OVSF-based scheme. This is because our scheme indeed provides a fast code assignment scheme.

We also define an improving rate IR to reflect the improving ratio by using our scheme and OVSF-based scheme. The improving rate is $IR = \frac{S_O - S_R}{S_O}$, where S_0 and S_R are the searching costs of OVSF-based and our schemes. The results of IR are displayed in 12(c) under the $Max\_SF = 128$ and $Max\_SF = 256$. For instance, the improving rate IR are 67.27% and 74.73% if the number of request data rates are 12 and 30, where the $Max\_SF = 128$ and $Max\_SF = 256$. Therefore, it is always beneficial to use our proposed protocol as demonstrated by the simulation results.

B. Performance of Blocking Rate

The simulation result of performance of blocking rate to reflect the effect of blocking rate vs. the number of request data rates as shown in Fig. 13. Observe that, let lines $CL3, CL4, CL5,$ and $CL6$ denote the default length of linear-code chains are 3, 4, 5, and 6, respectively. The line CG is represented as our scheme adopts the dynamic adjustment operation. First, one interest result is observed that if we use $CL3$, it may produce a large number of small-size linear-code chains. The blocking rate will be easily stable than using CLx, where $x \geq 4$. In addition, the blocking rate of $CL3, CL4,\ CL5,$ and $CL6$ are $CL5 > CL4 > CL3 > CL6$. This result shows that $CL6$ is too long such that the high blocking rate will be obtained, and the $CL3$ is too short, and the blocking rate of $CL3$ is still high. The best result of our simulation is adopted the $CL5$. In addition, the blocking rate of CG is lower than CLx, where $x \geq 3$. Therefore, the low blocking rate will be obtain if the scheme adopts the dynamic adjustment operation.

V. Conclusions

This paper presents a new channelization code scheme, namely ROVSF (Rotated-Orthogonal Variable Spreading Factor) to provide a fast searching code scheme to code assignment scheme in the WCDMA system. The OVSF-based scheme always takes lots of time to search for a feasible code. Our ROVSF-based scheme provides a fast code assignment strategy with lower searching cost based on new proposed code tree structure. Our ROVSF scheme offers the same code capability with the OVSF-based schemes, and with most of the properties of OVSF code tree. Finally, the simulation result illustrates that the fast-searching achievement of our ROVSF-based scheme. Future work will consider the multi-code assignment and re-assignment on the developed ROVSF code tree.

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