CHAPTER 1
INTRODUCTION

Spread spectrum concept in a wireless communication system [1] allows multiple users to occupy the same transmission band for simultaneous transmission of signals without considerable interference. It is a communication technique which transforms user signal into another form that occupies a larger bandwidth than the original signal would normally need. The process of transformation is known as spreading. It was initially developed for military and intelligence applications. Since last decade, spread spectrum systems have evolved from strictly military applications to commercial navigation and communication systems. The two prominent examples of this are: the Global Positioning System (GPS) navigation system, and the IS-95 (Interim standard) Code Division Multiple Access (CDMA) cellular telephone system. Spreading on a wide bandwidth makes jamming and interception more difficult. The bandwidth spread is accomplished by means of a code which is independent of the data and synchronized reception with the code at the receiver is used for despreading and subsequent data recovery. Spread spectrum signals are highly resistant to narrowband interference. This technique decreases the potential interference to other receivers while achieving privacy. To recover the transmitted data sequence at the destination mobile phone side, the same spreading code is used at the receiver. The spreading of signals depends upon spreading factor (SF). The incoming rate multiplied by spreading factor is called chip rate. The chip rate is always larger than the original data rate (symbol rate) i.e., $SF = \text{Chip rate} / \text{Symbol rate}$.

1.1 PROPERTIES OF SPREAD SPECTRUM

The purpose of transmitting a signal with a bandwidth wider than required is to improve the communications system performance. Spread spectrum systems have the following properties, which are utilized to improve performance relative to narrow band communication systems.

1.1.1 Multiple Access. A spread spectrum system allows multiple users to transmit simultaneously with same transmission bandwidth. This is accomplished by assigning to each user a unique code from a set of codes with low cross-correlation properties. Codes with low-cross correlation properties are also termed orthogonal spreading codes. Demodulation by
correlating the received signals with the desired code will recover the desired signal. The undesired signals will remain spread over the transmission bandwidth and will contribute noise power to the desired signal-to-noise ratio (S/N). Unlike time division multiple access (TDMA) or

![Diagram of Transmitter and Receiver](image-url)

**Figure 1.1:** Direct Sequence Spreading Spectrum System [1]

frequency division multiple access (FDMA) schemes, spread spectrum multiple access (SSMA) systems do not have a hard limit on the maximum number of users. Increasing the number of
users decreases the S/N ratio for existing users, and increases the bit error probability \((P_b)\) for all users.

1.1.2 Multipath interference reduction. A spread spectrum system is capable of reducing multipath interference. Multipath interference occurs when several copies of a transmitted signal arrive at a receiver due to reflection and refraction. The multiple signals arrive with different distortions in amplitude, phase, and time delay, which causes them to combine both constructively and destructively. This interference produces frequency selective fading of the received signal. Multipath interference is reduced by correlating the received signals with the spreading code to recover the desired signal. Multipath signals with large distortions in amplitude, phase or time delay will appear uncorrelated with the spreading code and will remain spread.

1.1.3 Privacy. A spread spectrum system offers some degree of privacy because the spreading code is required to recover the transmitted signal.

1.1.4 Anti-jamming. A spread spectrum system is capable of reducing the effects of narrowband jamming. This is possible because correlating the jamming signal with the spreading code in effect spreads the jamming signal while despreading the desired signal.

1.1.5 Low Probability of Intercept. Spread spectrum signals are difficult to detect, a characteristic termed as low probability of intercept (LPI), because the signal power is dispersed over a wide bandwidth. The transmitted signal is then difficult to distinguish from noise.

The ratio of transmitted bandwidth \((B_t)\) to information bandwidth \((B_i)\) is often used to approximate the performance gain of a spread spectrum system. The performance improvement offered by a spread spectrum system is termed processing gain \([2] G_p = \frac{B_t}{B_i}\).

1.2 DIRECT SEQUENCE SPREAD SPECTRUM (DSSS)

In DSSS, the data signal is modulated by a PN code sequence that effectively spreads the signal power over a wide bandwidth. The block diagram of a DSSS transmitter is shown in Figure 1.1 [1]. The data signal may be analog or digital. The PN spreading code is a digital signal that takes on values of +1 and -1, and the number of code bits per second is commonly called the chip rate \((R_c)\). The chip rate is typically much larger than the data symbol rate \((R_s)\), which results in the desired spreading in the frequency domain. The spreading factor (SF) of a DSSS system is
the ratio of $R_e$ to $R_s$. Multiple access is accomplished by assigning each user a unique spreading code from a set of codes with low cross correlation properties. The receiver recovers a desired signal from a group of spread signals by correlating with the correct spreading code. This demodulates the desired signal but not the signals of other users. The capacity of a DSSS system is interference limited. The spread signal of each user has properties similar to additive white gaussian noise (AWGN). Increasing the number of users effectively decreases the carrier to noise ratio (C/N) and increases the bit error probability ($P_b$), for all users. Multipath interference rejection is possible if the spreading codes have good autocorrelation properties. An ideal autocorrelation function has a value of zero outside the interval $[-T_c, T_c]$, where $T_c$ is the chip duration. A multipath signal that is delayed by greater than $2T_c$, much like a signal modulated with an uncorrelated spreading code is not recovered by correlation with the desired spreading code. DSSS provides privacy because the receiver must know the spreading code to demodulate the signal. DSSS reduces the effects of narrowband jamming because correlating with the spreading codes despreads the desired signal and spreads the jamming signal. Thus only a small amount of the jamming power remains in the signal bandwidth. LPI is provided since the spread signal has properties similar to AWGN and can be hidden in the background noise.

WCDMA radio interface fundamental operation is spreading. The spreading codes in WCDMA are grouped into two types: channelization and scrambling codes [3-4]. The channels in the forward link and reverse link use theses codes for transmission. Spreading is used in combination with scrambling. Scrambling is basically done on top of spreading needed to separate terminals or base station (BS). Scrambling codes are generated from the stream called pseudo noise sequences [1-2]. They do not affect chip rate or bandwidth. Channelization codes are shorter in length and are made from orthogonal function [5-6]. The orthogonality property of channelization codes makes it suitable for WCDMA systems. The use of channelization codes and scrambling codes are different in the uplink and downlink. In downlink, scrambling code is used to make differentiation for cells and channelization code is used to make differentiation of service between MS in the same physical channel. In the uplink, scrambling codes are used for user identification and interference mitigation while channelization codes are used for rate matching. For the uplink transmission, the scrambling codes and channelization codes are different. For the downlink transmission, same scrambling code is used for channels corresponding to each mobile station (MS). Hence, in the downlink transmission the efficient use
of channelization code becomes important. The channelization codes in WCDMA are OVSF codes. The OVSF codes are generated from the code tree generation given in [7-9]. One of the disadvantages associated with OVSF codes is that when a code is assigned to a new call, all of its parents and children codes are blocked from the assignment. This is due to the fact that the codes from root to leaf are orthogonal to each other. This problem leads to blocking of a new call even though the code tree has enough codes to support a new call. The code blocking leads to new call blocking. Basically, the new call blocking is due to two limitations of OVSF-CDMA termed as internal fragmentation and external fragmentation [10]. The external fragmentation is because of the availability of vacant codes in scattered form in the code tree. The internal fragmentation is due to the quantized nature of the rate handling capability of the OVSF code tree. WCDMA specifies four different traffic classes namely; conversational, streaming, interactive and background with different quality of service (QoS) requirements [11-14]. The typical QoS parameters are throughput, delay, power, and capacity etc. The traffic corresponding to each class needs to be treated differently. Real-time calls are always given higher priority compared to the non-real-time classes. The requirement of different QoS is discussed in [15-18]. The possible data rates for the WCDMA are \( R, 2R, \ldots, 128R \) (where \( R \) is 7.5kbps for downlink and 15kbps for uplink). The spreading factor \( (SF) \) for OVSF codes in the forward link is \( 4 \leq SF \leq 512 \) and \( 4 \leq SF \leq 256 \) in the uplink. The channel chip rate in WCDMA is fixed and is equal to 3.84 Mcps \( i.e. SF \times \text{symbol rate} = 3.84 \text{ Mcps} \).

1.3 REVIEW OF OVSF-CDMA

The channelization codes in WCDMA are OVSF codes. The channels in the uplink and downlink use these codes for transmission. OVSF codes are shorter in length and are made from orthogonal function. The orthogonality property of OVSF codes makes it suitable for WCDMA. The signals from two or more user equipments (UEs) in the reverse link are transmitted to the same base station (BS) in the cell from separate locations. This change in the distance gives rise to change in time for the signals to reach at the BS. The orthogonal property of the OVSF codes is disturbed due to different arrival times. Hence, the OVSF codes are not used for calls separation in the downlink. The facility to handle variable call rate is also incorporated in OVSF codes. In contrast to OVSF codes, scrambling codes are quite long (with the exception of the uplink of the
short scrambling code). Scrambling codes are generated from the stream called pseudo noise (PN) sequences [4-9]. In WCDMA, the requirement to have codes with high value of autocorrelation and low value of cross correlation. High autocorrelation properties are desired to recover the intended signal and to reduce the effect of multipath signals. The low cross correlation properties are required to minimize the effect of interfering signals. The PN codes and orthogonal codes individually do not have both good autocorrelation and good cross correlation properties [1-2]. Orthogonal codes are sets of binary sequences that have a cross-correlation coefficient equal to zero. A set of periodic signals $s_i(t)$ and $s_j(t)$ is orthogonal if

$$\frac{1}{E} \int_0^T s_i(t)s_j(t)dt = \begin{cases} 0, & i \neq j \\ 1, & i = j \end{cases}$$

(1.1)

where, $E$ is the energy of the signal given by

$$E = \int_0^T s_i^2(t)dt$$

(1.2)

In Equation (1.1), $T$ is the period of the signals $s_i(t)$ and $s_j(t)$, and $E$ is the signal energy as defined in Equation (1.2). The set of signals representing the orthogonal binary sequences 00 and 01 is shown in Figure 1.2. Walsh codes are orthogonal codes that are generated using a Hadamard matrix. A Hadamard matrix is a square matrix with the first row all zeros, and an equal number of ones and zeros on all other rows. A set of Walsh codes of length $n$ consists of the $n$ rows of an $n \times n$ Walsh matrix. That is, there are $n$ codes each of length $n$. The matrix is defined recursively as follows.
\[ W_1 = (0) \quad W_{2n} = \begin{pmatrix} W_n & W_n \\ W_n & W_n \end{pmatrix} \] (1.3)

where \( n \) is the dimension of the matrix and the over score denotes the logical NOT of the bits in the matrix. The Walsh matrix has the property that every row is orthogonal to every other row and to the logical NOT of every other row [1-2]. The length of the spreading code (N) is equal to the number of orthogonal codes. The ideal cross-correlation properties of orthogonal codes make them attractive for separating users in a DS-CDMA system. Orthogonal codes are only useful in synchronous systems, as they have extremely poor cross-correlation properties when not synchronized. The downlink of a CDMA cellular network is synchronous and systems such as IS-95 use orthogonal codes to separate users. However, multipath interference on the downlink results in unsynchronized signals at the receiver. In addition, orthogonal codes have poor autocorrelation properties making signal detection difficult.

\[ \begin{align*}
(C, C) \\
(C, -C) \\
(C) \\
(C, = (1) \\
C_{1,1} = (1, 1, 1, 1, 1, 1, 1, 1) \\
C_{4,1} = (1, 1, 1, 1, 1, 1, 1, 1) \\
C_{2,1} = (1, 1) \\
C_{4,2} = (1, 1, -1, 1, 1, 1, 1, 1) \\
C_{2,2} = (1, -1) \\
C_{4,3} = (1, -1, 1, 1, 1, 1, 1, 1) \\
C_{4,4} = (1, -1, -1, 1, 1, 1, 1, 1) \\
C_{8,1} = (1, 1, 1, 1, 1, 1, 1, 1) \\
C_{8,2} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,3} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,4} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,5} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,6} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,7} = (1, 1, 1, 1, -1, -1, -1, -1) \\
C_{8,8} = (1, 1, 1, 1, -1, -1, -1, -1) \\
\end{align*} \]

\[ SF = 1 \quad SF = 2 \quad SF = 4 \quad SF = 8 \]

\textbf{Figure 1.3.} OV3G code tree generation.
1.3.1 OVSF CODE TREE

The OVSF code tree generation is explained in Figure 1.3. For simplicity in code generation, we considered root code as layer 1, i.e. layer number increases from top to bottom of the code tree [7-9]. For a code in layer 1, $C_{1,1} = [1]$ and its two children codes in layer 2 will be $C_{2,1} = [C_{1,1}, C_{1,1}] = [1,1]$ and $C_{2,1} = [C_{1,1}, -C_{1,1}] = [1,-1]$ respectively. The codes in all the layers will be generated similarly from top to bottom to generate full OVSF code tree. In the assignment schemes utilizing OVSF codes for assignment, a code cannot be assigned to the incoming call if any of its children or parent code is already assigned to ongoing calls. i.e only one code can be assigned to a call in the path from root code to leaf code. In Figure 1.3, it is explained how a spreading factor varies in time domain from higher layer to lower layers and vice versa for data rate of a code. As we can see from Figure 1.3, $SF$ of children codes is repetition of parent code twice for one children and a combination of parent code and its complement for another children in same time limits to keep orthogonality. Consider an OVSF-CDMA system with $L$ number of layers and the code in layer $l$ is represented by $C_{l,n_l}$, where $1 \leq l \leq L$ and $1 \leq n_l \leq 2^{L-l}$. The maximum capacity of each layer and the system is $2^{L-l} R$. The number of codes in layer $l$ is $2^{L-l}$. The spreading factor $(SF)$ in layer $l$ is $2^{L-l}$. The data rate handled by the code in the layer $l$ is $2^{L-l} R$.

![Figure 1.4: OVSF Code tree with six layers](image-url)
1.3.2 CODE/CALL BLOCKING

The bit rate in OVSF-WCDMA is always quantized and is $2^{L-1}R$. With the increase in layer value from 1 to $L$, the rate handling capability doubles between two consecutive layers and becomes large as the difference between layers increases. This leads to internal fragmentation [10]. The two codes are assignable in the OVSF code tree if they are orthogonal, this leads to code blocking, a condition in which the new call cannot be accepted even though the system has enough capacity to handle new call. The maximum capacity of WCDMA system is always $2^{L-1}R$ ($R$ is 7.5kbps in the downlink). We limit our discussion in the downlink transmission only. Let $C_{l,n_l}$ represents a code in layer $l$, where $1 \leq l \leq L$ and $1 \leq n_l \leq 2^{L-l}$. The code blocking is explained using present status of Figure 1.4 where, the maximum capacity of the code tree is 32R. The used capacity is 9R (2R due to $C_{2,3}$, 4R due to $C_{3,4}$, R due to $C_{1,23}$ and 2R due to $C_{2,16}$). 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 rate capacity $16R$. This is called as *external fragmentation* and produce code blocking. The other cause of code blocking is *internal fragmentation*. This is due to the quantized rate handling capability of OVSF code tree. When a new user with rate $kR$, $k \neq 2^n$ arrives, the user requires a code with capacity $2^mR$, where $k < 2^n$ for minimum $m$. For example, we must assign $16R$ to a call request of $12R$. The capacity $4R$ ($16R-12R$) which is 33% of the required bandwidth is wasted and which increases with increase in difference of requested call rate and assigned code. One of the options to reduce this wastage is to use multiple codes which may increase the complexity and cost of the BS and UE. The relationship between user data rate, spreading codes and the channel data rate for three users with rates $R, 2R$ and $4R$ is shown in Figure 1.5.

Code blocking is the major drawback of OVSF-CDMA system and can be avoided using efficient assignment schemes, whereas, call blocking is the problem which is constituted by code blocking and blocking of call due to unavailability of vacant codes in code tree as explained in [19-20].

1.4 OVSF CODE ASSIGNMENT SCHEMES

In literature, a number of code assignment schemes are already proposed which aim at reducing code blocking probability. The performance of OVSF-CDMA can be improved using efficient code assignment and reassignment schemes, these schemes can be arranged in any of the following categories [21].

1.4.1 STATIC AND DYNAMIC CODE ASSIGNMENT SCHEMES

The static code assignment schemes rely on efficient placement of the code for the new call in such a way that the available vacant capacity of the tree is better utilized [22-24]. The dynamic code assignment schemes e.g. do code reassignments/replacements to reduce the code blocking [25-30]. This may increase the cost and complexity at the transceiver part.

The schemes available in literature can be broadly classified into two: the single code assignment and multi code assignment. The single code assignment scheme uses only one code from the OVSF code tree to handle new call [31]. The single code usage requires single rake combiner in the BS and UE. The multi-code assignment scheme uses multiple codes to handle
quantized or non-quantized data rates [32]. This requires multiple rake combiners equal to the number of codes required to handle new call which leads to increased complexity.

1.4.2 SINGLE CODE SCHEMES

Crowded first assignment (CFA), leftmost code assignment (LCA), fixed set partitioning (FSP) and recursive fewer codes blocked (RFCB) scheme 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) [22]. In LCA, code assignment is carried out from left side of the OVSF code tree [22]. In the FSP, the code tree is divided into a number of sub trees according to the number of input traffic classes and their distribution [27]. The RFCR scheme works on the top of CFA and the optimum code is the code which makes least number of higher rates codes blocked [33]. It resolves tie by recursively searching for best candidate. The adaptive code assignment (ADA) scheme divides the tree into small portions according to the arrival distribution reducing the number of codes searched for new calls [34]. The dynamic code assignment (DCA) scheme in handles new call using code reassignments [25]. 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 methods [35]. 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 numbers of groups equal to number of call arrival classes; (b) by deliberate rejection of those calls which may produce large code blocking for future higher rate calls. The number of codes searched 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 etc [36-37]. The fast dynamic code assignment (FDCA) reduces the number of code reassignments without causing degradation in the spectral efficiency of system [38]. The rearrangeable (dynamic) approach 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) [23]. Two priority based rearrangeable code assignment schemes were
proposed in [39] and [30], respectively. They 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 Fewer Codes Blocked (FCB) scheme [40] selects that vacant code which results in least new parents blocked which were free previously.

1.4.3 MULTI CODE ASSIGNMENT SCHEMES

Multi code assignment schemes [10], the multi code multi rate assignment (MMCA) scheme takes into consideration mobile devices with different multi code transmission capabilities and different quality of service (QoS) parameters [41]. The multi code scheme with code sharing is suggested to reduce wastage capacity or code blocking [42]. It combines scattered capacity (children codes of assigned codes) of already assigned codes to reduce code blocking problem. The multi code scheme formulates the optimum number of codes/rakes required to handle new call [43]. The multi code scheme derives the optimal code with constraints of allocated code amount and maximal resource wastage ratio [44]. It gives superior performance using two and three codes in a multi code with a crowded-group-first strategy. The code utilization and blocking benefits are significant for a resource wastage ratio of 40%.

1.4.4 ALLOCATION BASED ON REMAINING TIME

In most multimedia and real-time applications, such as video on demand, video conferencing, downloading music files, etc., the service time of the requests can be obtained a priori. Thus, the remaining time of each code occupied in the code tree is known. If calls with similar remaining time are allocated to the same subtree, then the whole subtree will be available for higher data-rate requests after the calls are released. As a result, the system is able to support more users and reduce the code blocking probability. The impact of the remaining time factor on the performance of the OVSF code allocation and propose two time-based allocation schemes that take the remaining time of each call as the main factor to assign and reassign codes is investigated. The calls with similar remaining time are allocated to the same sub tree [45].

1.4.5 NOVSF CODES

The non blocking OVSF (NOVSF) codes minimize the code blocking to zero [46-49].
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.

1.4.6 ROVSF CODES

The proposed rotated OVSF codes reduces the code assignment significantly compared to other methods [50]. It also reduces the code blocking significantly. They develop a new

\[ RC_{i,j-1} = (B) \]
\[ RC_{i,j-2} = (A,A) \]
\[ RC_{ii} = (A) \]
\[ RC_{ii} = (-B,B) \]
\[ RC_{ii} = (-B,-B) \]

\[ SF = i \quad SF = 2i \]
\[ SF = 1 \quad SF = 2 \quad SF = 4 \quad SF = 8 \]

(a)  
(b)  

Figure 1.6: (a) ROVSF code generation. (b) ROVSF code generation for four layers. (c) Relationship between ROVSF and OVSF code tree [52].

channelization code tree structure, namely; the ROVSF (rotated-orthogonal variable spreading factor) code tree, as illustrated in Figure 1.6 [51]. The main work of this investigation is to
exploit and justify the new properties of the ROVSF code tree. It shows that the ROVSF code tree offers the same code capability as the conventional OVSF code tree, ROVSF code tree has additionally code locality capability. With the code locality capability, a fast code assignment strategy is developed on the ROVSF code tree as compared to the existing code assignment schemes with lower search costs. A new code tree structure, namely an ROVSF (rotated-OVSF) code tree, the code capability of which is same as that of the traditional OVSF code tree is developed and single code placement and replacement schemes are developed for the ROVSF code tree to improve the code blocking probability and their code reassignment cost [50-52]. An OVSF code tree suffers from the internal and external fragmentation problem, in a similar way code assignment and reassignment schemes for ROVSF code tree suffers from these problems. A new multi code assignment and reassignment scheme for ROVSF code tree is proposed to efficiently reduce the internal and external fragmentation problems [53].

1.4.7 OTHER ASSIGNMENT AND REASSIGNMENT SCHEMES

More work is available in literature which focuses on different parameters of WCDMA networks using OVSF codes like; rakes utilization, throughput, quality of service (QoS), spatial diversity, spectral density etc.

A quality based assignment method in [54] proposes three assignment and reassignment strategies including fixed service data rates and considering a code limited system capacity. The paper carried out code assignment on the basis of available and guaranteed rate [55]. The OVSF codes support call rates that are powers of two i.e quantized rate and do not support many intermediate call rates. This reduces some flexibility in the allocation of code resources, and if non-quantized rates are assigned OVSF codes it may result in increased.

An efficient and fast channelization code assignment scheme (FEX scheme), by utilizing the code exchange and garbage collection technique, to reduce the blocking rate of the system [56]. The simulations demonstrated the effectiveness of this scheme by comparing to an "ideal system". The results also revealed the importance of the code exchange and multi-code property to greatly reduce the blocking rate of the system. Orthogonality constraint in the OVSF code tree may prevent efficient resource utilization. Code reassigning process can achieve an average of 20% gain of system throughput. Minimizing the code reassignments is essential in reducing the complexity of the wireless system. The design methodology and implementation techniques
proposes an efficient algorithm MIN in optimizing the reassignment cost [57]. The simulation results of the paper indicates that the MIN algorithm can reduce an average 60% of the reassignment cost compared to that of the heuristic method and it is feasible for implementing in BS or Radio Network Controller (RNC). An adaptive grouping code assignment is given to provide a single channelization code for any possible rate of traffic, even though the required rate is not powers of two of the basic rate [58]. It is based on the dynamic programming algorithm, the adaptive grouping approach forms several calls into a group. Then it allocates a subtree to the group and adaptively shares the subtree codes for these calls in the concept of time-sharing of slots during a group cycle time. Therefore, the waste rate and code blocking are thus reduced obviously while using a single rake combiner. Since the delay problem may be occurred in such a time sharing approach, so two schemes of cycle interleaving methods to reduce delay are also investigated. Numerical results indicate that the proposed adaptive grouping approach reduces significantly the waste rate and thus increases the system utilization. The proposed cycle interleaving scheme reduces data delay significantly. Like in every multiservice network, different rate calls in 3G systems will perceive dissimilar system performance if no measures are taken and the channelization code tree is treated as a common pool of resources. A complete sharing, complete partitioning and hybrid partitioning strategies to manage the code tree, and studies the performance in terms of blocking probability per traffic rate class and utilization of codes are introduced [59]. It turns out that fair access to codes by different rate calls and code utilization are conflicting goals, and that hybrid schemes can provide a compromise between these two extremes. The dynamic bandwidth allocation (DBA) scheme is an interesting scheme for future broadband wireless networks, including the 3G and 4G WCDMA systems [29]. A code division generalized processor sharing fair scheduling DBA scheme that exploits the capability of the WCDMA physical layer, reduces the computational complexity in the link layer, and allows channel rates to be dynamically and fairly scheduled in response to the variation of traffic rates. Deterministic delay bounds for heterogeneous packet traffic are derived.

The scheme efficiently utilizes multiple RAKE combiners in user equipments [60-61]. This approach finds in constant time all feasible codewords for any particular request, trying to minimize both rate wastage and code fragments. When working together with an independent code reassignment scheme, this approach has the same code request denial rate as previous work but has lower code management overhead. If code reassignment is not used, our approach still
has a bit of improvement on request denial rate. A guard code scheme has been introduced to favour ongoing calls over new calls in WCDMA systems employing OVSF codes as channelization codes [62]. The reservation of the codes takes place at the code management level and a new call(s) is accepted when available capacity of the systems is above threshold value defined for the scheme. The occupied codes state of the system and the transitions between the different states are modelled by a Markov chain. With the integration of an adaptive antenna array (AAA) at the BS, spatial diversity of mobile users can be utilized while assigning OVSF codes [63]. Users at distinct spatial locations probably fall in different downlink beams, and therefore, they can be assigned the same codes as long as the signal power received by the desired user is satisfactorily above the aggregate of interference signal powers. A new OVSF code allocation method is proposed with the AAA so called smart antenna based dynamic OVSF code allocation (SADCA) and robustness of SADCA over CCA and DCA schemes is also demonstrated [64]. The performance of DCA algorithm is evaluated and compared with other schemes [65]. Moreover, they propose a different algorithm for a more restricted setting [66]. It has been evaluated that DCA does not always return an optimal solution and that the problem is \(NP\)-hard. An exact time algorithm, and a polynomial time greedy algorithm is also given that achieves approximation ratio. A more practically relevant version is the online code assignment problem, where future requests are not known in advance. The flexibility index is defined to measure the capability of an assignable code set in supporting multirate traffic classes. Based on this index, two single-code assignment schemes, nonrearrangeable and rearrangeable compact assignments, are proposed [67]. Both schemes can offer maximal flexibility for the resulting code tree after each code assignment. Two scalable DCA schemes with call admission control for OVSF-CDMA systems are studied [68]. The proposed schemes generate an average data throughput of the system close to that of the optimal scheme while demanding much lower design and implementation complexity than the optimal scheme. The capacity partitioning scheme partitions the capacity of code tree into several mutually exclusive subsets of resource and assigns each subset of resource to a group of users in proportion to the corresponding traffic load. The class partitioning scheme partitions the set of service classes into mutually exclusive groups of classes and assigns a subset of the total resource to the corresponding group of classes. In either case, the call requests that belong to each subset of resource or each group of classes are served independently of others by the optimal DCA.
The proposed an adaptive simulated annealing genetic algorithm (ASAGA) in which population is adaptively constructed according to existing traffic density in the OVSF code-tree [69]. Also, the influences of the ASAGA parameters (selection, crossover and mutation techniques and cooling schedules) were examined on the dynamic OVSF code allocation problem. The proposed scheme outperforms conventional code assignment (CCA) and DCA schemes when compared for code blocking probability and spectral efficiency utilization, genetic algorithm (GA) and simulated annealing (SA) algorithms are also tested with ASAGA [70-71]. The simulation results show that the GA and SA provide reduced code blocking probability and improved spectral efficiency in the system when compared to the CCA and DCA schemes. Finally, the more system performance results, the more computational load. Ad hoc networks are wireless networks without fixed infrastructure. Each mobile node in the network may move arbitrarily, and therefore network topology changes frequently and unpredictably. Since, the OVSF codes are originally used as the channelization codes in the DS-CDMA system of International Mobile Telecommunication (IMT)-2000, previous schemes are centralized and cannot be applied directly to fully distributed systems such as ad hoc networks. Totally, six distributed code management schemes are proposed and three of them heavily exploit two techniques: code reassignment and code tree management [72]. Simulation results show that these schemes, with the help of the techniques, reduce the call blocking rate dramatically. Four different code assignment schemes presents namely; random scheme, left most and crowded first for the OVSF code tree and compared their performance [73]. It also proposes a new technique that selects the best method. The procedure in the selective one is based on using fast algorithm for low traffic loads until a defined load is demanded and selects the best algorithm for it's best performance in higher loads.

A call admission and code allocation schemes are proposed to provide service differentiation in the forward link of wideband code-division multiple-access (WCDMA) systems [74]. In particular, the paper proposes multiple leaf code reservation (MLCR) schemes, where different numbers of OVSF leaf codes (i.e., codes of the lowest layer of the OVSF code tree) are reserved to differentiate users with different bandwidth requirements. Leaf codes are only reserved for as long as the call admission process lasts. Once the decision of whether a new request is admitted or not has been made, a code dereservation procedure is carried out to increase flexibility in the code assignment phase. The performance of these MLCR strategies
with/without code reassignments is then evaluated. Analysis shows that MLCR schemes are also useful in improving fair access among different traffic classes. In addition, perfect fair access among requests with different data rates can be achieved when code reassignments are jointly employed with the proposed OVSF-code reservation schemes. The drawbacks are pointed out which are inevitable due to multi code assignment, high complexity of handling multiple codes, and increasing the cost of using more rake combiners at both the base stations and mobile nodes [75]. Therefore, to improve performances on these parameters an adaptive grouping code assignment is proposed to provide a single channelization code for any possible rate of traffic, even though the required rate is not powers of two of the basic rate. Based on the dynamic programming algorithm, the adaptive grouping approach forms several calls into a group. Then it allocates a subtree to the group and adaptively shares the subtree codes for these calls in the concept of time-sharing of slots during a group cycle time. An adaptive grouping code assignment herein to provide a single channelization code for any possible rate of traffic, even though the required rate is not powers of two of the basic rate [76]. Based on the dynamic programming algorithm, the adaptive grouping approach forms several calls into a group. Then it allocates a subtree to the group and adaptively shares the subtree codes for these calls in the concept of time-sharing of slots during a group cycle time. The adaptive grouping approach reduces significantly the waste rate and thus increases the system utilization [76]. To achieve high data rate transmission in personal multimedia communications, 3G wideband CDMA systems (WCDMA) adopt the (OVSF) code tree for channelization codes management. However, it can waste system capacity. One good solution causes two drawbacks, long handoff delay and new call setup delay, which can degrade significantly the performance of 3G cellular systems. An adaptive efficient partition algorithm with the Markov decision process (MDP) analysis approach to provide fast handoff while reducing the waste rate significantly [77]. There are two primary motivations for the proposed MDP approach. First, based on the current state of the OVSF code tree, an adaptive partition algorithm is proposed to determine multiple codes for new connections. After determining these codes, the MDP analysis is adopted to assign least cost codes for them, which results in reducing a large number of reassignments. Second, to support fast handoff processing, the MDP approach assigns a single channelization code for each handoff connection. Thus, the dropping rate and grade of service (GOS) can be reduced. The approach yields several
advantages, including the lowest GOS, the least waste rate, and the least number of reassignments. Finally, the optimal number of RAKE combiners is deduced.

An OVSF code management scheme called the region division assignment (RDA) scheme that divides total capacity in regions for a call request of particular rate [78]. A new call will check a vacant code in its region only. The performance of the OVSF code assignment schemes based on Universal Mobile Telecommunication Systems (UMTS)/IMT-2000, i.e., the CCA, the DCA, and RDA are compared [79]. It was shown that RDA gives better performance than DCA and CCA in terms of the packet dropping probability under heavy traffic conditions. An extensive performance comparisons among the three proposed OVSF code assignment schemes, that focuses on two performance measures, i.e., the number of simultaneous voice conversations and the calculation time. Hybrid code allocation (HCA) is the scheme that has features of both DCA and RDA, it mitigates the code blocking more than RDA [80]. HCA, at first, performs RDA and then if code blocking happened, reassigns codes in the region which borrows a code and assigns a code to the request. A placement optimality is presented using a novel graph model, constrained independent dominating set problem (CIDP), the algorithm of it addresses both OVSF code placement and replacement issues at the same time and achieves placement optimality in linear time [82]. Chaotic sequence with low cross correlation are generated using phenomenon which is useful for spreading in CDMA. The bit-error-rate (BER) performance of logistic-map based chaos spreading codes with other spreading codes is compared. RAKE receiver and time-invariant multipath channels are used for the simulations. The chaos codes outperform m-sequences and Gold codes. Although the OVSF codes always outperform the chaos codes in AWGN environment, there are cases with time-invariant multipath channels, in which the BER of the chaos codes are better [83]. To improve the system performance while handling bursty internet traffic DSCH and HSDSCH channels are used in current mobile networks. OVSF codes use is limited to data transfer time of the session. Here, through the use of a multiplexer or scheduler, a queue and a buffer, a Traffic Model Scheduler (TMS) in layer 2 / RLC of HSDPA is introduced to reduce the OVSF code usage in HS-DSCH and which could save them [84]. The transform domain code division multiple access (TD-CDMA) which synthesizes the excellence of the transform domain communication system (TDCS) and the code division multiple access (CDMA) technology. The TD-CDMA has the characteristic of low probability of intercept (LPI) and the capability of multiple access (MA), and it’s great potential
to be applied in the cognitive radio (CR) contexts. The channelisation codes used in Universal Mobile Telecommunications System (UMTS) belong to the family of OVSF codes. They are organised according to a code tree structure. OVSF codes are primarily used to preserve orthogonality between different channels. The objective of code assignment is to enhance statistical multiplexing and spectral efficiency of WCDMA systems supporting variable user data rates. The performance of OVSF code assignment schemes, in terms of code blocking probability are compared in [85]. OVSF codes have been used for image spreading before transmission as it solves the synchronization problem and minimizes the effect of unwanted noise during transmission in Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM). Rayleigh fading channel has been used in the proposed scheme [86]. An Orthogonal Frequency and Code Division Multiplexing (OFCDM) technique. OFCDM can be envisaged as an OFDM system with two-dimensional (2D) spreading in time and frequency domains [87]. the performance of OFCDM and OFDM systems as an application in 4G systems. 2-D spreading approach is compared which is based on an adaptive load balancing with Markov decision process (which is denoted by ALM). The ALM approach consists of three phases [88-89]. In a system with Code Division Multiple Access (CDMA), the proposed technique exploits one code channel as the training sequence for channel estimation purposes. In a noisy environment, this technique performs better than the pilot based, thanks to the averaging effect of the noise impairment[90].