CHAPTER 2

LITERATURE REVIEW

In the present chapter, the technical aspects and previous related works in Cognitive radio, DS-CDMA system and spreading codes are discussed.

2.1 COGNITIVE RADIO

Recent studies on the spectrum utilisation of wireless communications revealed that a vast portion of spectrum remains unused for 90% of the time as investigated by Devroye & Tarokh (2008). Hence efficient utilization of radio frequency spectrum resources has received greater attention. This necessitates the need for highly flexible and intelligent terminals that can support different standards in different frequency bands as discussed by Jondral (2007). As stated by Chakravarthy (2008), spectrum efficiency can be improved by Dynamic Spectrum Access which falls under three categories namely Dynamic exclusive use model, Open sharing model and Hierarchical Access model. In the dynamic exclusive use model, the licensed user has the right to sell the spectrum and select the technology. In this model, spectrum efficiency is improved by Dynamic Spectrum Assignment (DSA). Open sharing model aims at efficient use of licensed bands used for television broadcasting and unlicensed Industrial, Scientific and Medical (ISM) radio band. Hierarchical access model, a spectrum sharing approach, allows sharing of spectrum between the licensed and unlicensed user. It is based on two approaches namely, underlay approach and overlay approach. Out of all these
spectrum access methods, hierarchical access model is found to be compatible with the Federal Communications Commission (FCC) regulations and existing wireless systems.

Cognitive Radio is a technology which falls under the category of hierarchical access model. The two well known cognitive radio standards are Standards Coordinating Committee 41 (SCC41 or P1900) and IEEE 802.22. SCC41 deals with developing architectural standards and heterogeneous network management protocols. IEEE 802.22 focuses on usage of CR-based air interface in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands. Lu et al (2012) have mentioned that the application of CR in femtocells is adopted by the standard IEEE 802.16m which focuses on an increase in the indoor coverage area and spectrum efficiency. CR technique can be used in emergency situations such as natural disasters and accidents to locate the survivors since it provides an efficient and reliable communication.

The spectrum bands that can be used by the SU are divided into two categories namely spatial spectrum hole and temporal spectrum hole. Temporal spectrum hole indicates the region of spectrum band without any PU transmission during a particular period and it can be used by SU for transmission. Spatial spectrum hole indicates that the portion of the spectrum band which is outside the area of PU’s transmission. The different types of spectrum sensing techniques are matched filtering detection, energy detection and feature detection as mentioned by Chakravarthy (2008).

As reported by Batalama et al (2011) and Yi et al (2010), the two modes of operation in CR networks are supervised learning (co-operative mode) and unsupervised learning (co-existence mode). The two techniques based on supervised learning are interweave communications and spectrum overlay. Interweave communications, an opportunistic spectrum access scheme, utilises the temporarily unused spectrum holes. This requires fast and
reliable spectrum sensing operation. In overlay systems, SU cancels the interference of PU by sensing PU’s message and using sophisticated coding techniques such as dirty paper coding. In these methods, CR or SU requires prior knowledge of PU’s behaviour to reduce the effect of mutual interference. In underlay approach, both the licensed and unlicensed users are allowed to share the spectrum concurrently.

In the opportunistic or overlay or coexistence mode of operation of CR, the unused spectrum portion is allocated to SU by spectrum sensing algorithms. This may suffer from the disadvantage of not detecting the presence of an active PU or mistakenly making the decision of the presence of a PU. Furthermore, the spectrum sensing has to be continuous and the spectrum allocation to the SU must be dynamic resulting in a continuous change of transmission frequencies of the SU. Moreover the SU will not get a chance to transmit for the entire duration when the PU accesses the channel. From this point of view, underlay approach is quite advantageous as the dynamic spectrum change is not present and the SU is allowed to access the entire spectrum. Hence, underlay approach is suitable in situations having a fast change in spectral conditions. However, the drawback in this approach is that the SU is not allowed to transmit at high power levels even when the PU is idle as reported by Elezabi et al (2009) and Rawat & Yan (2011).

Quan et al (2008) have expressed that in the underlay approach based on unsupervised learning, there is no sharing of information between PU and SU. In underlay systems, SU shares the PU’s spectrum resources without any apriori knowledge about the PU under the constraint that the interference from SU appearing as noise at the PU end should not degrade the performance of PU. This interference reduction constraint can be met either by employing multiple directional antennas or by spreading the signals over a wider bandwidth as in spread spectrum or UWB communications. Moreover,
Feher (2006) has also suggested that in CR systems, it is possible that the reactivated licensed PU may cause corruption to the data transmissions of the SU. This requires antijamming coding techniques to maintain a reliable CR system as suggested by Yue (2008). These two conditions of maintaining low interference power level and having privacy between the PU and SU can be achieved by using DS-CDMA system employing a separate codebook at the PU and SU end as suggested by Yi et al (2010). This type of operation is called individual decoding mode. Privacy between PU and SU can be achieved if these code sets have a more evenly spread frequency spectrum. In an underlay system, interference from SU to PU can be minimised by reducing the SU transmitted power and its data rate.

Elezabi et al (2009) have discussed that PU interference at the SU end can be minimised by interference minimizing code assignment. This is done by assigning a spreading code to the newly incoming SU such that the interference from the already existing PU and SU is minimised. The code selection is based on minimizing the mean square cross correlations between the signature codes and the received signal.

A coexistence mode cognitive network without any apriori knowledge about PU network is developed by Batalama et al (2011). The periodic total square correlation interference is used as a metric to protect the co-channel PU. The PU signature codes are identified at the SU end using blind signature estimation methods. The Quality of service of SU is then maintained by optimizing its transmitting power and signature codes.

Reduction of mean square cross correlation and optimized spreading code assignment to the secondary user in a CR network is achieved using ant colony optimization by Shafiee et al (2011). Rajabzadeh & Khoshbin (2012) have designed spreading codes for a Multi-Carrier DS-CDMA (MC-DS-CDMA) overlay network. Generalised Eigen Value
decomposition method and an iterative algorithm are used to design these spreading codes.

An interference avoidance based underlay system employing spreading sequence based transmission scheme is discussed by Menon (2007). In this technique, the SU spreads the signal over the entire bandwidth and avoids transmitting in the frequencies in which they can sense static radio transmissions. Interference is avoided by sequence adaptation, adaptive frequency hopping and notched-transmission techniques. It is also shown that the performance of the DS-CDMA system utilizing the above concepts is enhanced if the bandwidth of the system is increased.

An interweave CR system based on a hierarchical wide-band two-dimensional spread MC-DS-CDMA is described by Chang & Kuo (2010). Orthogonal Variable Spreading Factor (OVSF) code tree is shared by PU and SU. Spreading codes are classified into three categories namely white, gray and black. White code is not occupied by the PU, black codes are occupied by the PU and gray codes are occupied by the SU who is either inside or outside the coverage area of PU. Hence, interference can be reduced by careful assignment of gray and black codes. Comparatively, interference from gray code is less than the black codes. This is achieved by utilising a dynamic spectrum access algorithm that combines transmission power control mechanism, call admission control and MAI-coefficient-aided management of the spreading code resources.

Performance of Orthogonal Frequency Division Multiplexing (OFDM) and MC-DS-CDMA systems employing WH codes in an UCR network is investigated by Phasouliotis (2010). It has been shown that MC-CDMA outperforms OFDM in an UCR system. Application of cyclostationary signatures in an OFDM based CR system is explored by Grammenos & Yang (2009). This is done by embedding a cyclostationary
signature sequence to a set of subcarriers in an OFDM signal. It is suggested that combining this signal with the Autocorrelation division multiple access method seems to reduce the cochannel interference and MAI.

Suppression of spectral side lobes in MC-DS-CDMA systems employing WH codes is discussed by Lin et al (2011). It makes use of the fact that the asymptotic spectral decaying characteristic of WH codes exhibit regularity. This characteristic can be described by the Hamming and derivative weights of code index of the underlined WH codeword. This property is used to assign WH codes to the users such that the spectral side lobe is suppressed.

Driouch et al (2012) have developed an interference temperature management approach to protect PU from SU interference. This is achieved by restricting the transmitted power of SU in a specific frequency band and geographic location. Interference avoidance is achieved by advanced technologies such as Multiple Input Multiple Output (MIMO) systems equipped with smart antennas for beamforming and multihop CR system.

In multihop CR network, relays are used to assist transmission between the SU transmitter and receiver at a reduced power level. This results in reduction of interference due to SU appearing at the PU end as suggested by Lu et al (2012). A two phase transmission protocol based on decode-and-forward relaying concept is discussed by Han et al (2009) and Manna et al (2010). SU acts as a relay and transmits the PU and SU information during the first and second phases respectively.

A CR network operating in a hybrid underlay/overlay mode within the coverage area of three operators and sharing their spectrum is reported by Manosha et al (2011). The CR network base station is equipped with relays operating in synchronous/asynchronous mode serving two purposes. They are
enhancing the performance of low coverage areas of PU and maximising the SU capacity by switching their operating frequencies between the licensed and unlicensed band at different time slots depending on the spectrum availability.

Spectrum underlay cognitive network described by Driouch et al (2012) attempts at having a separate cognitive base station equipped with multiple antennas to serve the SU. The cognitive base station uses an antenna assignment algorithm such that the quality of service and the number of SU’s is maximised with the limited power level allotted to the SU, i.e., keeping the SU interference power level at the PU end within an acceptable level. The relationship between interference threshold power and secondary link transmission rate, primary transmission power in a CR underlay system is studied by Wang & Zhao (2008). It is shown that the secondary link transmission rate becomes constant after a certain threshold power limit.

Chakravarthy (2008) has shown that the signal to noise ratio improvement and interference can be avoided by transmit/receive waveform diversity. This is achieved by using Transform Domain Communication System where an interference free spectrum is first created by identifying and notching the frequency bands containing jamming and interference signals. A complex polyphase code applied to the OFDM subcarriers in this clean spectrum and taking the inverse Fourier transform results in the generation of time-domain Fundamental Modulation Waveform (FMW). The data to be transmitted is then modulated using FMW.

Shao & Beaulieu (2011) describe the design of direct and time hopping sequences that adapt to the channel conditions in an Infra-red DS-CDMA UWB system. These sequences are designed such that they create nulls in the frequency band according to the spectral occupancy information
provided by the CR. This technique results in a significant reduction of interference between PU and SU.

Safatly et al (2012) have achieved generation of adaptive UWB pulses in the clean spectrum by three techniques namely Parks-McClellan algorithm, radial basis function neural network and a reconfigurable band stop filter. The effects of CR underlay group size, methods for underlay PSD allocation, BER threshold and power control in a Multi Band-OFDM UWB system is examined by Mayers & Raju (2011).

Another recent technique employing the underlay approach is the Femtocells as described by Humblet & Richardson (2010) and Chandrasekar & Andrews (2008). Femtocells or home-base stations are an intelligent cellular data access point which aims at improving the indoor coverage area, spectral efficiency and increasing the data rate in cellular wireless networks. Femtocell under laid inside a macrocell forms an underlay network. Moreover, a femtocell is developed on top of wideband CDMA based or orthogonal frequency-division multiple access system based macrocellular systems. Unlike CR, mobile users in femtocells are licensed users sharing the spectrum of macrocells. Since the same spectrum is shared, care should be taken to reduce the interference between femtocell and macrocell users. The most commonly used techniques to reduce this type of cross-tier interference in a DS-CDMA system employing macrocell/microcell network are antenna beamforming techniques, power control techniques, attenuation techniques and using different spreading bandwidths for the macrocells and microcells as stated by Kang et al (2003).

Improvement in two tier interference avoidance between a microcell embedded inside a macrocell and spectrum efficiency is achieved by proper assignment of white and gray codes to the microcell users as discussed by Chang (2012). MAI coefficient is used to find the white and gray
codes that offer less intra and intercell interference to the microcell users and
does not harm the macrocell users. It is described that when this technique is
combined with substream deactivation, MC-DS-CDMA system is suitable for
CR systems.

2.2 DIRECT SEQUENCE CODE DIVISION MULTIPLE
ACCESS SYSTEM

According to Shannon’s channel capacity theorem, the capacity of
a communication channel is a trade-off between transmitted signal power and
bandwidth. It states that the channel capacity can be increased either by
increasing the transmitted signal power level keeping bandwidth fixed or
transmitting the signal over a wider bandwidth at a fixed transmission power
level as reported by Haykins (1998).

In spread spectrum communication, the bandwidth ‘W’ of the
transmitted data signal is much greater than the information rate ‘R’ in
bits/sec. Hence, the bandwidth expansion factor (W/R) is much greater than
unity. This large redundancy enables the spread spectrum signals to overcome
the severe levels of interference encountered in certain radio communication
channels in spite of transmitting the signals at low power levels as stated by
Haykins (1998). These signals are also used to obtain accurate time delay and
velocity measurements in radar and navigation. As reported by Parker et al
(2003), the DS-CDMA technique is used in various applications such as
cellular, microcellular, indoor and satellite communication systems. DS-CDMA system supports variable and high data rate transmission services.

As explained by Haykins (1998) and Li et al (2008), all the users
transmit at the same frequency in CDMA systems where the individual users
are identified by assigning distinct signature codes to them. In this technique,
the frequency spectrum of a data signal is spread using a code that is
uncorrelated with the signal and unique to every user. The major advantages of DS-CDMA technique are high spectral efficiency (due to its low frequency reuse factor) and robust performance (due to its powerful processing gain). However, the major drawback of a DS-CDMA system is that it is an interference limited system.

Multi-Path Interference (MPI) occurs due to the large number of resolvable paths between the transmitter and receiver. This can be reduced by choosing signature codes that have low autocorrelation side lobes. MAI effect can be reduced if the cross correlation between any two codes is less than the autocorrelation value at delay zero. As stated by Jalil et al (2009), the interference effect and error probability depends on the autocorrelation and cross correlation properties of the spreading codes such as mean square autocorrelation, mean square cross correlation, maximum absolute value of cross correlation function and maximum absolute value of out of phase autocorrelation function. Message privacy is achieved by the randomness noise like appearance of the spread spectrum signal that occurs due to spreading by signature codes. Thus, the performance of a DS-CDMA system depends on the type of spreading codes used as reported by Scutari et al (2008). Moreover, a large code set size enhances the system capacity in a CDMA system.

2.3 SPREADING CODES

Depending on the number of code sequences assigned to each user, the spreading codes can be classified into two types namely, unitary codes and complementary codes as specified by Chen (2005).

2.3.1 Unitary Codes

Unitary codes work on the basis of one code per user. It can be divided into two sub-categories namely, orthogonal codes and quasi-orthogonal
codes. The most widely used orthogonal codes are Walsh-Hadamard (WH) codes employed in Interim Standard-95 (IS-95), cdma2000 systems and OVSF codes used in 3G cellular standards. The different types of quasi-orthogonal codes are Gold codes, Kasami codes, m-sequences, Bent codes and wavelet codes. The Orthogonal and Quasi-orthogonal codes are found to be more suitable for synchronous and asynchronous communication respectively.

Quasi-orthogonal codes possess a correlation zone having values of almost zero around the zero phase shifts as specified by Ricardo et al (2007). Maximal length sequences or m-sequences, Gold codes and Kasami codes belong to this class of codes. Maximal length sequences or m-sequences are the shift-register sequences having the maximum possible period for an n-shift register. As explained by Garg (2007), m-sequences can be generated from the output of a linear feedback shift register with certain feedback logic which depends on the primitive generator polynomial. These codes have good autocorrelation properties but their cross correlation properties are poor. These codes can be generated by Galois feedback generator and Fibonacci feedback generator.

Gold codes are constructed from the modulo-2 addition of a preferred pair of m-sequences and are applied in Universal Mobile Telecommunication System (UMTS) to distinguish between the different channels. These codes possess better cross correlation properties than the m-sequences. Construction of M-ary Gold codes using mutually orthogonal complementary sequences derived from bipolar Gold codes is suggested by Garg (2007). These codes are found to be more immune against MPI than the ordinary Gold codes.

Kasami sequences can be classified into two classes namely, small set and large set. These sequences have period N=2^n-1, where ‘n’ is a non-
negative and even integer. These sequences are generated by modulo-2 addition of two m-sequences namely ‘p’ and ‘q’ where ‘p’ is a m-sequence and ‘q’ is a decimated sequence of ‘p’. The small set of sequences possess optimal cross correlation properties satisfying the Welch’s lower bound as specified by Chen (2005).

Generation of a new family of quasi orthogonal sequences belonging to the class of pseudo-noise even balanced sequences known as quasi-orthogonal Bose Chaudhuri Hocquenghem (BCH) derived sequences is described by Ricardo et al (2007). These sequences are generated from the existing odd balanced BCH sequences and has correlation properties better than the existing quasi-orthogonal codes.

Bent sequences are widely used in cryptography due to their high linear span and optimal correlation properties. As described by Lempel (1982), the columns of Hadamard matrix represent bent functions. Hence, bent sequences can be generated by fast transform algorithms similar to WH transform. Variable and constant length bent sequences generated from the WH matrix are applied in wireless advertising based on CDMA systems. It is shown by Rashid et al (2001) that these codes offer better Bit Error Rate (BER) performance and an improvement in the number of users supported.

Construction of wavelet packet spreading codes by applying shifts and dilations to various wavelets is reported by Chen (2001). These codes are capable of mitigating frequency selective fading and providing frequency diversity. They find applications in multi-code spreading.

Akansu & Poluri (2007c) have generated a new orthogonal code family called as Walsh like codes by computer search algorithm. These codes have lengths that are multiples of four. New families of varying power spreading codes with flexible code lengths designed by Akansu & Poluri (2007a) was using the Karhunen-Loeve transform (KLT). The code sequences
in these sets correspond to the eigen vectors or KLT bases generated from the autocorrelation or auto covariance matrix of spread spectrum AR model, Auto Regressive Moving Average (ARMA) model and the power spectral density functions obtained from the spectrum of Gold and Walsh like codes. Multiple level integer code families with various short and long code lengths are generated by Akansu & Poluri (2007c) using the Brute Force Search Algorithm and taking the Kronecker product of two orthogonal spreading code families. Generation of these codes using an orthogonal transmultiplexer structure is given by Akansu & Poluri (2007b). BER performance of these codes are shown to outperform Walsh codes and is marginally superior to the Gold codes in a Rayleigh channel.

Usha & Sankar (2012) have constructed 4! Walsh code set of any length using 4-bit Gray and Inverse Gray codes. Design of balanced code sequences using multi-objective genetic algorithm is described by Yin & Tang (2005). It is based on rearranging the columns of the Hadamard matrix according to order-based chromosomes and different sets of sequences were obtained for various autocorrelation and cross correlation values. The construction of Hadamard matrices from binary and quadriphase Golay complementary pairs based on Goethals-Seidel array is discussed by Wysocki & Wysocki (2002). These codes offer better BER performance in an asynchronous DS-CDMA system than the WH codes.

Application of FFT as spreading codes in the Carrier Interferometry OFDM (CI/OFDM) system is proposed by Anwar & Yamamoto (2006). These CI/OFDM codes are capable of achieving high efficiency, low complexity and Peak to Average Power Ratio (PAPR) reduction. Su & Yu (2012) combined Walsh Hadamard Transform (WHT) and DFT and it is computed using a butterfly structure. This is implemented in hardware with iterative architecture, which reduces the number of computation stages. The
complexity is thereby reduced which can be used in WHT-OFDM applications.

Channel matched spreading codes for MC-DS-CDMA system that considers the statistical characteristics of the channel are designed by Shi et al (2007). Under fading, unitary polyphase codes are mathematically proven to be optimal polyphase codes in terms of MAI. Polyphase codes include the most widely used binary and quarternary spreading codes as special cases.

Generation of periodic and non periodic polyphase codes with the autocorrelation function having one main peak and very small side peaks are described by Frank (1980). As reported by Pereira & DaSilva (2009a), (2009b) perfect sequences have all out of phase autocorrelation coefficients equal to zero and possess low maximum absolute value of periodic cross correlation. These sequences are more suitable for asynchronous DS-CDMA system since they provide fast convergence in equalisers, synchronisation and channel estimation. The different types of polyphase perfect sequences are the generalized chirp-like polyphase sequences, the Frank sequences, Zadoff-Chu sequences, Generalised Chu polyphase sequences. Frank codes are widely used for pulse compression in radar applications.

2.3.2 Complementary Codes

Complementary Codes (CC) work on the basis of one flock per user. The different types of Orthogonal CC are Complete CC, Extended CC, Super CC, Column-wise CC, Inter-Group CC, Non-orthogonal CC are Primitive CC and Pair-Wise CC. These codes are generated by using orthogonal codes as the seed code. As an example, Hadamard matrix is used as the seed code and BER performance of the resulting code set in a DS-CDMA system and space time coded DS-CDMA system is obtained. These codes are more resistant against MPI and MAI and offer a better BER
performance than the conventional CDMA system spreading by WH, Gold
codes. However, the set size of these CC are less than the traditional unitary
codes. A spreading code design approach namely Real Environment
Adaptation Linearization (REAL) approach is developed by Chen (2005). It
considers the constraint of generating the interference free codes. It also
provides an insight into the properties of orthogonal complementary codes.

Increase in the set size of complete CC based on orthogonal Zadoff-
Chu polyphase sequence is described by Lu & Dubey (2004). This is achieved
without affecting the autocorrelation and cross correlation properties of the
original CC, by taking the Kronecker product of Hadamard matrix with the
CC. These codes are shown to be suitable for both uplink and downlink
transmission in a MC-DS-CDMA system. In multiphase or polyphase CC
pairs, the individual elements of each sequence are constant in amplitude and
have variable phase parameters. Formation of multiphase CC pairs based on
kernels of lengths 2, 3, 10, 26 and Barker codes are discussed by Sivasamy
(1978). Barker codes, a discrete version of continuous chirp, possess less
autocorrelation side lobe amplitudes and uniform spectrum as reported by
Golomb & Scholtz (1965). An eleven chip barker sequence is applied in IEEE
802.11b for the 1 and 2 Mbit/sec rates.

The design of the Zero Correlation Zone sequences (ZCZ) is an
extension of generating complementary sequences as stated by Weng et al
(2004). When compared to CC their cross-correlation and out-of-phase
autocorrelation functions are all zeros within a region called the Interference
Free Window (IFW) with an increased set size. These codes are found to be
suitable for synchronous and quasi-synchronous systems. Another type of
code that possesses IFW is the Large Area Synchronized (LAS) codes.
Construction of LAS codes with increased duty cycles by absolute and
relative encoding is studied by Choi & Hanzo (2002). The secondary codes
applied for this encoding are Barker sequences and polyphase complementary pairs. These codes are found to increase the capacity of CDMA networks. Interlaced complementary codes using Barker codes as building blocks are constructed by Fam & Sarkar (2007). These codes have unity peak side lobe amplitude and presents superior performance in frequency selective fading environments.

The construction of ternary mutually orthogonal complementary sets is based on two approaches namely, iterative approach and combination approach as described by Wu et al (2004). These codes are applied in a DS-UWB system where the same information is transmitted over four channels after spreading with the sequences from the ternary complementary set. At shorter code lengths, BER performance of these codes in a DS-UWB system in a multi-path fading environment is better than the 31-length Gold codes. Hence, these codes are found to be suitable for high data rate applications.

Complementary codes are used as signal sets in Complementary Code Key (CCK) modulation that employs IEEE 802.11b specification as stated by Pursley & Royster (2007). It utilises M-ary orthogonal keying (e.g. Quadrature Phase Shift Keying) and polyphase complementary codes. This type of modulation provides high data rate transmission suitable for wireless local area networks. Moreover, enhancement in performance of CCK modulation by employing pairwise-complementary biorthogonal signal set derived from Hadamard matrix is also investigated by Pursley & Royster (2009).

As reported by Otero & Hernandez (2011), OFDM and MC-CDMA offers immunity against narrowband interference and robustness in frequency-selective fading channels. The major drawback in these systems is the high Peak to Average Power Ratio (PAPR) of the transmitted signals which results in reduction of battery lifetime. The various techniques to reduce PAPR in
OFDM are utilizing codes with low PAPR, clipping the OFDM signal before amplification and filtering, block coding, partial transmit sequences, selected mapping and tone reservation.

PAPR is mitigated in MC-CDMA by spreading code selection and subcarrier scrambling. PAPR reduction in SFBC MIMO MC-CDMA downlink using WH codes based on user reservation approach is studied by Otero & Hernandez (2011). In this approach, peak reducing signals selected from the orthogonal WH spreading code sequences are added to the signal to be transmitted to reduce PAPR. Since these newly added signals are orthogonal to the transmitted signal, no side information from the transmitter or modification at the receiver is needed.

Reduction of PAPR in an OFDM system utilizing constellation shaping based on Hadamard matrices is proposed by Mobasher & Khandani (2004). Hadamard constellation shaping provides simple encoding algorithm and it can be concatenated with other PAPR reduction techniques such as SLM thereby avoiding the need to transmit the side information and hence improved spectral efficiency.

2.4 ROLE OF LATTICE FILTER IN RECONFIGURABLE RADIO

As discussed above and suggested by Akansu & Poluri (2007b), spreading code families with varying code lengths and good performance can be utilised in SDR, CR and sensor systems. Moreover, FFT block is needed to implement an OFDM system and spreading code block is needed in a DS-CDMA system. Since Kronecker product can be used to implement both the above mentioned operations, the same block can be reconfigured to receive either a DS-CDMA signal or an OFDM signal.
Thiagaraajan et al (2007) have reviewed the reconfiguration of the various processing blocks in the transceiver structure such that a single terminal can support multiple air interfaces such as MC-DS-CDMA, Orthogonal Frequency Division Multiple Access and Interleaved Frequency Division Multiple Access (IFDMA) systems. The following blocks are suggested for reconfigurable transceiver namely repetition block, spreading block, serial to parallel conversion and parallel to serial conversion blocks, pre-transform block, zero insertion block, scrambler, interleaver and deinterleaver, addition and removal of cyclic prefix and equalization.

Linear equalisers in wireless communications can be implemented using tapped delay line or transversal filter structure and lattice filter structure. As suggested by Rappaport (2009), equalisers implemented using lattice filter structure offers the advantages of high numerical stability and faster convergence. Moreover, depending on the time dispersive channel characteristics, the filter length can be dynamically increased or decreased without stopping the operation of the equaliser which is not possible with a transversal filter structure.

As reported by Ozden & Tahir (2012) lattice filters are a suitable choice for spectrum sensing in Digital Signal Processing (DSP) and Field Programmable Gate Array (FPGA) chip based SDR implementations. Design of multichannel ARMA lattice filters using modified Levinson Durbin algorithm for spectrum sensing in CR is also suggested.