CHAPTER 1

INTRODUCTION

1.1 GENERAL

The growing demand to provide high data rates in wireless communication system necessitates the need for a flexible and efficient use of spectrum resources. Attar & Nakhai (2008), Mitola III & Maguire (1999) and Mitola III (2000) have described Cognitive Radio (CR) as an emerging technology that aims at efficient utilization of radio frequency spectrum resources. It allows unlicensed Secondary Users (SU) to share the radio spectrum accessed by the licensed Primary Users (PU) without causing harmful interference to PU. Yi et al (2010) stated that in a CR system, based on underlay approach, maintenance of low interference power level and privacy between the PU and SU can be achieved by using spread spectrum communication and Ultra Wide Band (UWB) communications. Li et al (2008) mentioned that the interference resist capability and spectral efficiency of a spread spectrum communication system, based on Direct Sequence Code Division Multiple Access (DS-CDMA) depends on the correlation properties and available number of spreading codes. The present thesis discusses the construction of new sets of spreading codes similar to Walsh Hadamard (WH) codes and generation of WH codes using a Reconfigurable Lattice Filter (RLF).

1.2 MOTIVATION

Kronecker products are found to be quite useful in the development of fast computation algorithms for signal processing applications as reported
by Regalia & Mitra (1989) and Moon & Stirling (1999). They have also suggested that the recursion formula of generalized kronecker products with matrix permutations results in the generation of varieties of discrete unitary transform matrices such as Discrete Fourier Transform (DFT), Haar transform and Hadamard transform. Kronecker products also find applications in multirate filter banks used in sub band coding of speech signals. Kronecker sequences enable rapid code acquisition due to their patterned structure which is a desirable feature in ranging and secured military applications than the conventional pseudo noise sequences. Karkkainen (1998) also expressed that using such Kronecker codes allows the implementation of a matched filter receiver for sequences with longer lengths.

Akansu & Poluri (2007b) have suggested that spreading code families with varying code lengths and good performance can be utilised in Software Defined Radio (SDR) and CR and sensor systems. Moreover, Fast Fourier Transform (FFT) block is needed to implement an Orthogonal Frequency Division Multiplexing (OFDM) system and spreading code block is needed in a DS-CDMA system. Since kronecker product can be used to implement both the operations, the same block can be reconfigured to receive either a DS-CDMA signal or an OFDM signal.

Moreover, in an Underlay CR (UCR), separate codebooks are needed to distinguish PU and SU. The enhancement in spectrum efficiency in a DS-CDMA system depends on the number of users supported which in turn is determined by the code set size. Moreover, reconfiguring the physical layer is essential in reconfigurable receivers if the same terminal needs to be used for diverse applications and in different networks. This motivates the need to construct codes based on kronecker product recursion and generation of WH codes using RLF.
1.3 OBJECTIVE OF THE THESIS

WH codes are widely used in wireless CDMA applications as spreading codes for synchronous downlink transmission. It is simple to construct these codes based on Sylvester construction. The construction method is based on kronecker product recursion. Hence, the number of users supported can be increased with less effort since the code length and set size can be doubled by adding an additional stage of kronecker product operation.

The objective of the present research is to generate spreading codes similar to WH codes for spreading the information of SU in a spreading based UCR system employing DS-CDMA technique. It also aims at analytically studying the Multiple Access Interference (MAI) effect of the proposed codes in a DS-CDMA system and UCR system in an Additive White Gaussian Noise (AWGN) channel. It also aims at designing a RLF so that they can be applied in reconfigurable radios. The proposed lattice filter can be used to generate WH codes, represent a first order AR Gauss Markov process and function as a matched filter. Here the term Walsh codes and WH codes are used interchangeably.

1.4 RESEARCH WORK DONE IN THIS THESIS

In the present research, modified WH code sets are generated by using different basic kernel based on Complementary Sequence Set (CSS), kernels generated by code concatenation and permutation of existing WH codes and formation of WH codes from orthogonal bent functions. These codes are assigned as signature codes to SU in UCR system and their BER performance is obtained in an ordinary DS-CDMA system and UCR system. The significance of WH code generation based on kronecker product recursion is that the code length and set size can be doubled by adding an additional stage of kronecker product operation. Moreover, CR based
technology aims at efficient utilisation of all the available resources with the reconfigurable ability to self-organize, self-plan and self-regulate as suggested by Pawelczak et al (2011). Further, generation of WH codes from the lattice filter structure representing the Auto Regressive (AR) model of WH codes and AR model of first order Gauss Markov process is discussed. Bit Error Rate (BER) performance of the matched filter realized by the proposed lattice filter structure in a DS-CDMA system is also described.

1.4.1 Modified WH Code Generation by Code Concatenation and Permutation

New sets of binary code families are obtained from the existing WH codes based on the concept of code concatenation and permutation. They are generated by modifying the basis sequences in any one stage of kronecker product recursion of the original WH code generation. Hence, these codes can be generated by reconfiguring the original WH code generator. In reconfigurable receivers, reconfiguring the physical layer is essential if the same terminal needs to be used for diverse applications and in different networks as described by Mahmoud et al (2009). Implementation compatibility of the proposed codes with the WH codes enables them to be used in reconfigurable receivers such as CR and SDR. Codes of length 16 generated based on this method are designated as z161, z162, z163 and z1, z2, z3, z4, z5, z6, z7 respectively.

1.4.2 WH Like Code Generation from Four Complementary Sequence Set (CSS)

In general, WH codes of even lengths are only used as spreading codes in DS-CDMA system. In the present work, a novel method of forming codes similar to WH codes with odd lengths is generated. In general, two CSS of length 2 is used as a basic kernel to construct WH codes. Here, four CSS of
length 3 is used as a basic kernel and a code set with code length 27 and code set size 64 is generated. This code set size is almost double when compared with WH code of length 32. Codes of length 27 generated based on this method is designated as z27.

1.4.3 Modified WH Code Generation from Bent Sequences and Orthogonal Bent Functions

Two sets of orthogonal codes are constructed from fourth order Bent sequences and orthogonal bent functions respectively. Codes of length 16 generated based on this method are designated as B16 and F16 respectively. The seed codes used for the construction of these sequences are obtained from the Hadamard matrix. Moreover, a method to generate F16 codes by modifying the existing WH code generator using T-flipflops is also proposed.

1.4.4 Sequence Modification using Diagonalisation Method

The correlation properties of the modified WH codes based on code concatenation and permutation, CSS, Bent sequences and orthogonal Bent functions can be improved by multiplying the proposed code matrix with an orthogonal diagonal matrix as proposed by Seberry et al (2003). The diagonal elements are chosen from the diagonal elements applied by Wysocki, Williamson-Hadamard spreading sequences and orthogonal bent functions. The resulting code sequence set is designated with the extension Wysoc, Will, Bent1 and Bent2 respectively in their corresponding code names.

1.4.5 Analytical Method to Study the MAI Effect and Quadrature Carrier Multiplexing (QCM) in UCR System

Analytical results to study the MAI effect of the proposed codes in a DS-CDMA system is obtained based on the earlier analysis suggested by
Pursley & Sarwate (1977). These results are further extended in the present research to study the MAI effect between PU and SU signature codes in an UCR system. From the analytical equation, it was observed that MAI depends on the cross correlation properties of the spreading codes used. Since both PU and SU information are transmitted at the same carrier frequency in an UCR, further improvement in isolation between them can be achieved by using quadrature or orthogonal carrier multiplexing. The carrier frequencies at the PU and SU end are kept orthogonal to each other.

1.4.6 Generation of WH Code using Reconfigurable Lattice Filter and its Application in DS-CDMA System

In the present work, a novel method of generating WH codes using lattice filter structure is proposed. The entire WH code set can be generated by changing the reflection coefficients without modifying the filter structure. This feature ensures reconfigurability and enables them to be used in SDR. Moreover, this reconfigurable structure can be used as a matched filter for multiuser detection in a DS-CDMA system. BER performance of a DS-CDMA system employing a correlator receiver and the proposed matched filter receiver for despreading is simulated in an AWGN plus flat fading Rayleigh channel. The results of simulation showing the generation of WH codes from the AR model of first order Gauss-Markov process is also obtained.

1.5 ORGANIZATION OF THE THESIS

The thesis is organised as follows,

Chapter 2 describes the literature survey about the previous related works in CR, UCR, DS-CDMA system and spreading codes.
**Chapter 3** provides a detailed description of the performance measures to study the correlation properties of the spreading codes, analytical signal to noise ratio, merit factor and error probability in terms of these autocorrelation, cross correlation measures in a DS-CDMA system in an AWGN channel. It also discusses about the generation of the proposed codes from the existing WH codes based on code concatenation and permutation. The details of implementation and the results of correlation properties, merit factor, BER performances in a DS-CDMA system are also discussed.

**Chapter 4** discusses about the construction of proposed codes based on CSS. The results of simulation showing their BER performance in a DS-CDMA system under AWGN and AWGN plus flat fading Rayleigh channel conditions and various performance measures are also obtained.

**Chapter 5** describes about the generation of proposed codes based on Bent sequences and orthogonal Bent functions and their correlation properties, BER performances in a DS-CDMA system are also discussed.

**Chapter 6** deals with improving the correlation properties of the proposed codes by diagonal modification method. BER performances of these codes in a DS-CDMA system are also obtained.

**Chapter 7** deals with the application of the proposed codes in an UCR system employing Quadrature Carrier Multiplexing. Moreover, an analytical equation to calculate the error probability in an UCR system for an AWGN channel is also derived and the results are obtained. The results of simulation showing the BER performance of the WH and proposed codes in an UCR system are also obtained.

**Chapter 8** describes the generation of WH codes using a RLF and the application of this lattice filter as a matched filter in a DS-CDMA system.
Generation of WH codes from a lattice filter representing a first order Gauss-Markov process is also obtained.

**Chapter 9** concludes the work done. It discusses the results of the research of the thesis and also suggests research avenues that can be further explored.