Chapter 1

Introduction

Research in cognitive radio field has been gaining much attention in recent years due to its promising aim to solve the spectrum under-utilization problem. In Cognitive Radio Networks (CRNs), it is allowed for an unlicensed user, also called a Secondary User (SU), to dynamically use the frequency bands of a licensed user, or a Primary User (PU), under condition of causing no harm to the PU's transmission [1]. This can be satisfied if an efficient sensing technique is used to detect the existence of a PU signal.

As shown in Fig. 1.1 CRNs mainly consist of a group of secondary nodes that opportunistically share the frequency spectrum and in some cases there exists a central entity to manage frequency sharing called Fusion Center (FC). Secondary nodes are cognitive radios that sense the licensed portions of the spectrum in search for access opportunities under condition of preserving the licensed transmission to have the highest priority. Cognitive radios are able to change its transmission parameters, as transmitting power, accessed frequency, modulation scheme ... and so on, such that an acceptable Quality of Service (QoS) is achieved and successful licensed transmission is preserved.

Spectrum sensing is the process with the highest priority in the spectrum access process. Spectrum sensing is the operation of detecting transmission opportunities for SUs by monitoring the activity of PUs [2]. The main goal for any spectrum sensing technique is to detect the presence of the PU as fast as possible with high detection probability and low probability of false alarm to insure acceptable network reachability level to the secondary network and avoiding performance degradation of PU's transmission.

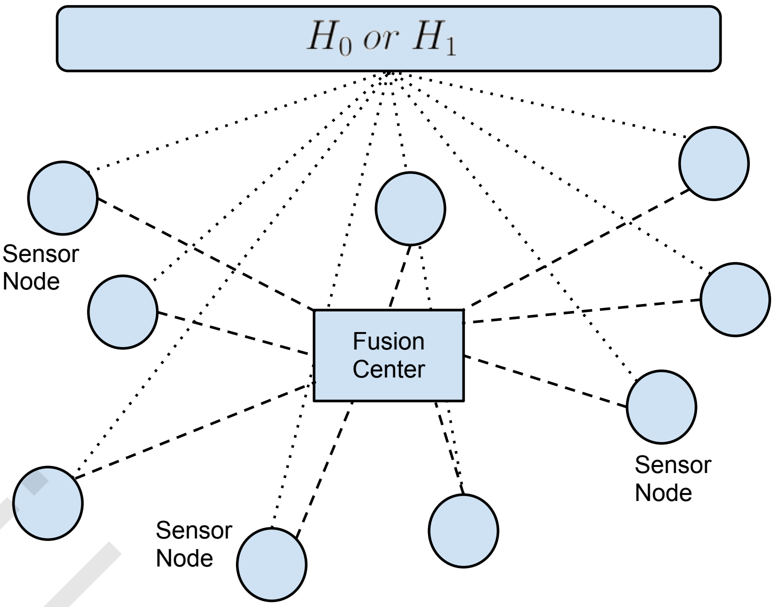

FIGURE 1.1: Architecture of a CRN

In addition to spectrum sensing, there must be a ready and efficient handover technique that is capable of estimating the interference over the PU and switching to another frequency channel once the interference is found to be harmful to the PU's transmission [3].

In this thesis, the primary signal of interest is the TV signal (whether analog or digital). This is due to the fact that Federal Communications Commission (FCC) has expressed its interest in permitting unlicensed access to white spaces in the TV bands (54-890 MHz) [4]. This interest is due to the good propagation characteristics of the TV bands. They have large bandwidth channels (6, 7 or 8 MHz) and high transmitting power. This allows SUs to access large bandwidths (when TV signal is inactive) and it enables SUs to transmit without affecting TV signal significantly. Additionally, being a much under utilized band means that it can be accessed by other users when it is not used by TV operators. Building on this interest, the IEEE has formed a working group (IEEE 802.22) to develop an air interface for opportunistic secondary access to the TV spectrum which is our interest in this work.

Fuzzy-logic based approaches are the main contribution in this thesis. Fuzzy reasoning is a mathematical tool particularly appropriate to make decisions in situations where the available inputs are in general uncertain and imprecise or qualitatively interpreted. Additionally, when the information available about the decision making inputs is mostly heterogeneous, fuzzy logic is able to transform heterogeneous and qualitative information into homogeneous membership values, which can then be processed through a proper set of fuzzy IF-THEN rules. Utilizing a Fuzzy Inference System (FIS) to deal with parameters is completely flexible and highly accurate. It controls the decision making process and eliminates the problem of rigidity in dealing with values [5]. More information about FIS can be found in Appendix A.

This thesis consists of three main parts. In the first part, a fuzzy-based signal classification technique is proposed that is able to differentiate between TV signals and other secondary signals that might be using the licensed TV channels. This classification is useful in many applications where knowing the characteristics of the active user (Transmission power, modulation scheme, ... etc) helps monitoring its performance and reaching efficient spectrum utilization. From another perspective, knowing the nature of the active user in the sensed channel will lead to some kind of cooperation among cognitive (secondary) nodes to schedule the dynamic spectrum access and efficiently share the frequency bands. The proposed technique utilizes two sensing algorithms, Energy Detection Method (EDM) [6] and Correlation Based Method (CBM) [7], in parallel. Then, the main contribution of this part is to combine the results of EDM and CBM using an FIS system to decide whether the sensed signal -if any- is a TV signal or another signal. This proposed technique shows capability of signal classification in case of analog TV signal (PAL) and digital TV signal (DVB-T).

The second part is concerned with the handover process. Concurrent transmissions of PUs and SUs may occur only if the aggregate interference caused by the SUs at the PUs is maintained below some acceptable threshold. Based on the results collected during the spectrum sensing operation, spectrum has to be managed. If the SU is causing harmful interference to the PU's transmission, the frequency channel has to be quickly vacated and the SU needs to switch to another frequency channel. This switching process is called spectrum handover. The way how SUs make the decision of handover is a challenging problem [3]. The challenges raising in a cognitive radio scenario can be properly met by using techniques based on incomplete knowledge representation and qualitative reasoning. In particular, a fuzzy-based approach is proposed to deal with the incompleteness, uncertainty and heterogeneity of a cognitive radio scenario. Based on this proposed approach SUs can autonomously and automatically make the decision to change its frequency channel.

The last part in this thesis is concerned with trying to distribute the sensing task among sensing nodes in CRNs. Generally, SUs, in centralized CRNs (those that include a central managing entity called a Fusion Center (FC)), share the sensing information with each other through the FC to reach a unique solid global decision among the cooperating nodes. When the spectrum of interest is a wide-band, the sensing process at each node consumes much time plus the time required to process the nodes' individual decisions at the FC to reach a global decision. This time consumed reduces the time available to access the spectrum and thus the spectrum utilization efficiency decreases. Therefore, it is required to distribute the sensing task of wide spectrum over cooperating nodes where each node has access to different set of channels. The sensing task is distributed among the secondary nodes to allow each node to sense only a subset of the whole frequency range. Two distribution approaches are presented in this part. They not only aim to reduce the time required for sensing and processing but also aim to reduce the overall probability of sensing error by choosing the best candidate nodes for each channel. The first presented approach is a fuzzy-based assignment algorithm that uses the contribution of each node in the global probability of sensing error and the SNR of the reporting sub-channel of each node to select the best candidates for the sensing process. The second approach applies the Hungarian algorithm on a task-agent assignment problem.

Performance evaluation using MATLAB simulations of the three proposed approaches in this thesis has proved accurate results and enhanced performances.