CHAPTER 1: INTRODUCTION

Data Communication Networks find their extensive utility in national security, commerce, education sector, social media interactions, voice telephony, Internet usage and multimedia streaming. Further, in recent times there has been an exponential growth in the number of its users and their demands. On the other side, with extensive developments in the field of microelectronics, wireless transmitters and receivers have become very popular and hence increased demand for electromagnetic spectrum usage. Since much of the spectrum has been licensed to wireless networks, spectrum scarcity is an unavoidable consequence. However, a recent survey of licensed networks [1] shows that a large portion of spectrum is underutilized. If only one can have a mechanism to identify the underutilized spectral bands and utilize them effectively, there is a large free electromagnetic spectrum out there for future applications. Cognitive Radio (CR) technology addresses the issues and techniques of utilizing the otherwise underutilized spectral bands.

1.1 Cognitive Radio

Joseph Mitola [1] coined the name cognitive radio (CR) which is a self-reconfigurable and will make radios to switch operations and functions. As per his vision, a CR is not simply programmable as per the situation but it is trainable too. He also outlined that through cognitive cycle it will reconfigure itself and changes in the outside world. With reconfiguration capabilities and cognition, CR is able to attain good experience to the user and improves quality of information. Haykin defines CR[2] as a radio which is aware of surroundings, which understands and analyses its surroundings, based on learning it will adaptively change its parameters in real-time for better spectral efficiency and reliability.

The Federal communications commission (FCC) gives its definition as: “A cognitive radio (CR) is a radio which interacts with the environment in which it operates and change its parameters accordingly but neither field programmable nor having software are requirement for majority of cognitive radio”.

Regardless of differences in both application and scope, two major characteristics are common in most definitions. They are: cognitive adaptive behaviour and re-configurability according to the situation. Cognitive adaptive behaviour refers to the ability to adapt without any a priori programming but through learning.

From the above, the prime capabilities of CR functionality can be categorized as follows:

- Agile and Flexible on the fly: CR should have ability to change the operational parameters which is not the case in current multi-channel multi radio (MC-MR). When CR’s are built on Software defined Radios (SDR’s) full flexibility is achieved. Another possibility to attain flexibility is reconfigurable antenna technology.
- Sensing: CR should have ability to observe and measure, which includes spectral occupancy. Sensing plays an important role for the device to change its operation as per the sensing algorithm findings according to the environment.
- Learning and adaptability: CR should be capable to analyse the data which has obtained from sensing unit, recognise patterns, based on the observations done on new environment change, internal operational behaviour with the help of learning mechanism and pre-coded algorithms.

1.2 Cognitive Radio Networks

Cognitive Radio Networks (CRNs) are those networks that have all their constituent nodes or most of the nodes as CRs. Cognitive radio networks (CRNs) are becoming popular recently because of their ability to explore the underutilised bands. Two kinds of users will be there in the CRNs: licensed or primary users and unlicensed or secondary users. Primary users are the ones who have been allocated certain spectrum bands by authorities and secondary users are the ones who are in need of frequency and are unlicensed. If secondary user (SU) wants to access the primary user (PU) band, it should not cause interference to PU and SU can utilize the band when PU is not accessing the band. If primary user comes back, SU has to vacate the band and look for another free licensed band. Coexistence of PUs and SUs in a network is dependent on Sensing, Decision, Sharing and Mobility of spectrum. In the current work, emphasis is on improving the quality of service of cognitive radio networks. The following figures 1.1 and 1.2 shows the architecture and transceiver block diagram of Cognitive radio network. We can observe three network access types

CR Network Access: CRs can access their own base station on both licensed and unlicensed spectrum bands

CR AdHoc Access: CRs can communicate with other CRs through an ad hoc connection on both licensed and unlicensed spectrum bands.

Primary Network Access: CRs can access primary base station through the licensed bands.

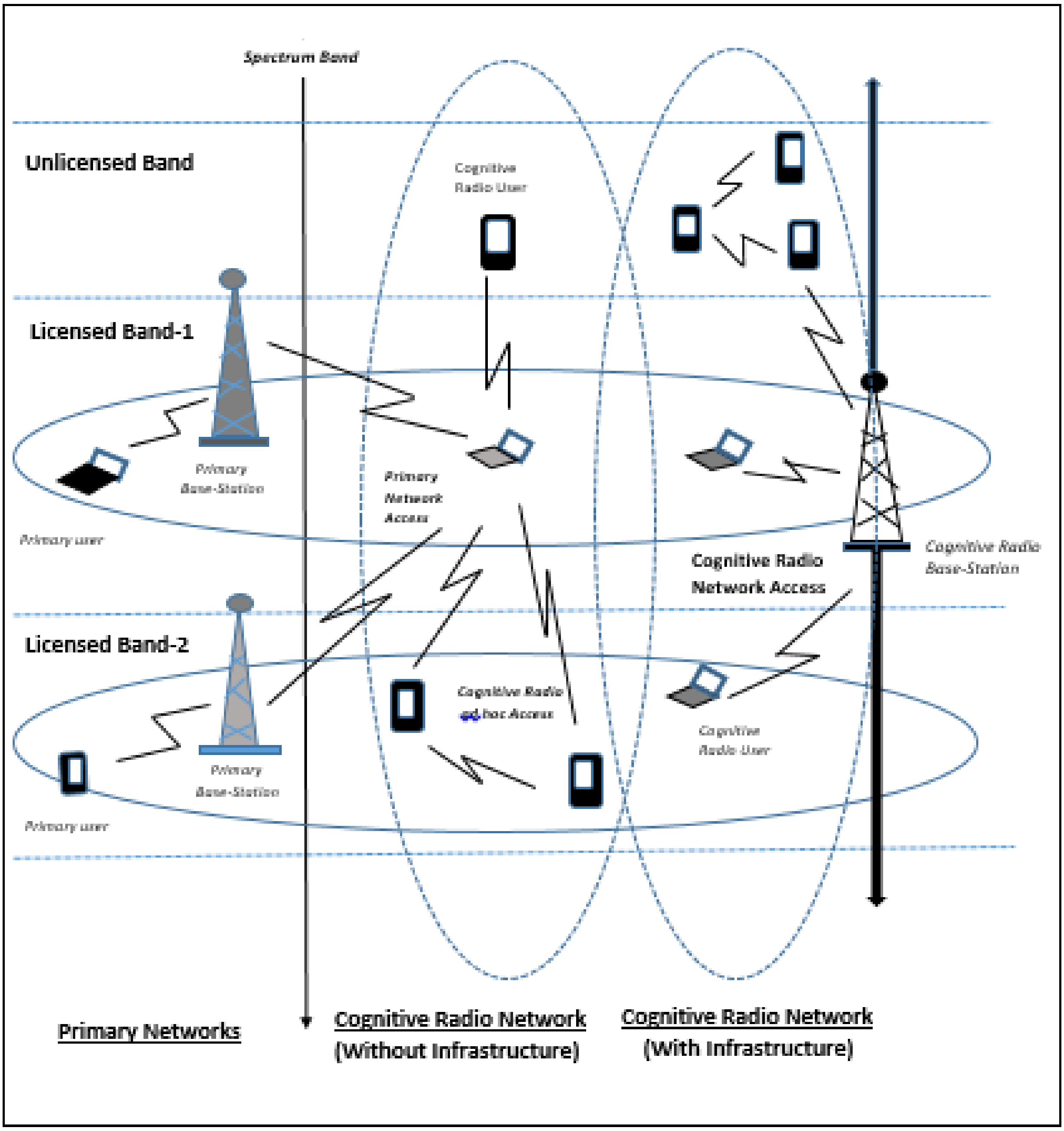

Figure 1-1: Cognitive Radio Architecture

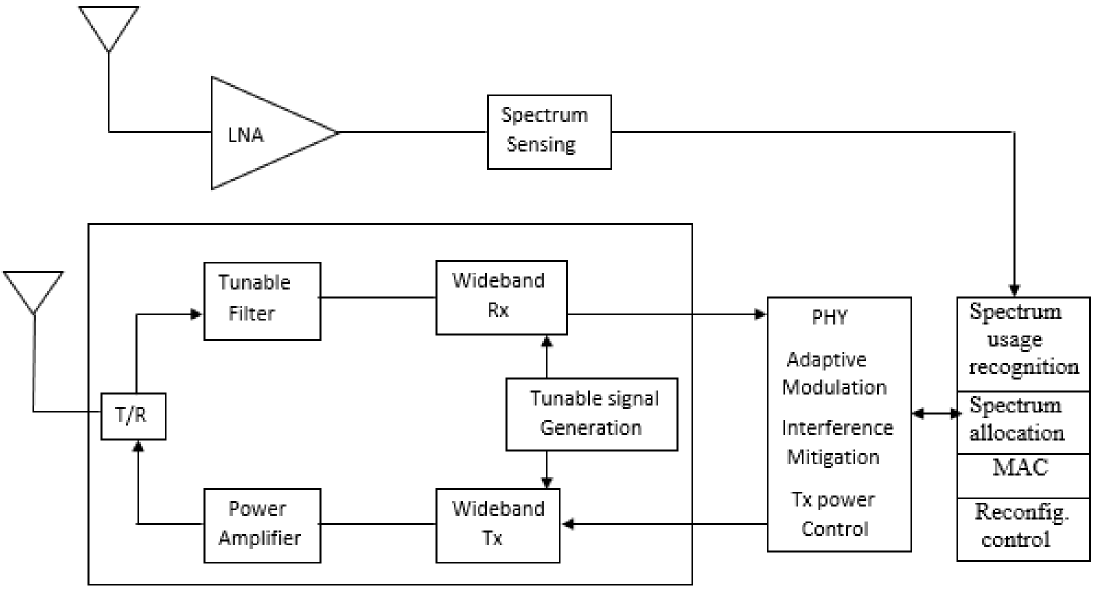

Figure 1-2: Transceiver Block diagram of Cognitive Radio Networks

1.3 Applications of CRN

Since its inception, CR technology has attracted profound attention in the research community. Following are some of the applications where cognitive radio is included and implemented. They are: Cognitive radio based Femto cells [3], Military application [4], Cognitive radio based sensor networks [5], Cognitive radio based Machine to Machine (M2M) communications [6], Cognitive radio based smart grids [7], Disaster response networks [8], Cognitive radio for Internet of Things [9], Aeronautical communications [10], Vehicular Networks [11], Cognitive radio based Satellite Communications [12] and Green Energy Powered Cognitive radio networks [13]. Furthermore Cognitive radio technology is also adopted in fifth generation (5G) wireless communication systems [14]. As the requirement of spectrum is increasing there is substantial growth in Cognitive radio applications and the surveys have focussed more on standardising networks of IEEE 802.22, 802.11af , 802.15.4 and 802.19.1 [15].

1.4 Quality of Service in CRNs

Quality of service (QoS) of any system is said to be great when it guarantees low latency, high throughput and certain level of successful sessions. Like all the communication systems available in the market, CRNs should also provide best Quality of service to the end users. QoS Provisioning is much difficult in CRNs than traditional wireless networks [16]. Especially in overlapping CRNs, QoS needs to be optimised at the user terminal without causing interference.

QoS objectives of CRNs are similar to traditional networks because CRNs are also wireless in nature. As the spectrum access is undedicated in nature, there are separate schemes and techniques for CRNs. Hence, QoS objectives are classified into three different categories as mentioned below [17]:

1. **Spectrum Efficiency:** A measure of the supported data rate over a given bandwidth and its units are (bits/sec/Hz).
2. **Delay:** The total time taken by packets to get transmitted from source to destination
3. **Throughput:** which is defined as how many data packets are successfully delivered

1.5 Essential Components of CRNs from QoS perspective

The main components of CRN, whose performance would influence the QoS of entire CRN are shown in Figure 1.3 and explained below:

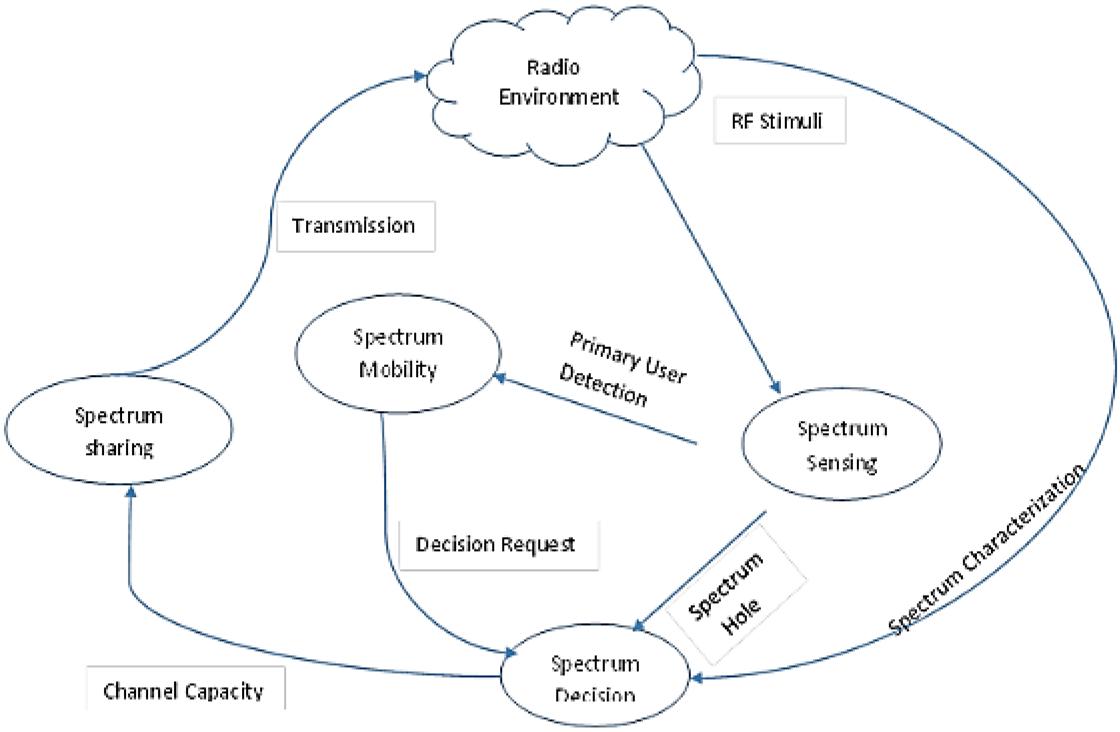

Figure 1-3: Cognitive Radio Cycle

1. ***Spectrum Sensing*****:** Detection of vacant channels is performed by this component and the detected vacant channels are utilized by overlay or underlay strategy [17]. Hence, spectrum sensing plays an important role in cognitive radio network performance. Two main elements that influence the QoS in sensing stage are: a) Sensing accuracy b) Sensing efficiency, which in turn are dependent on the choice of the spectrum sensing methods. The currently available spectrum sensing methods are:

   a. Energy Detection based sensing
   b. Matched filtering based sensing
   c. Cyclo stationarity based sensing
   d. Waveform based sensing

e. Radio Identification based sensing

f. Cooperative sensing and other sensing methods

Of all the above methods, the energy detection based method is the simplest, robust and does not need any a priori knowledge about the underlying signals. This however has a higher rates probability of misdetections and false alarms. To reduce the probability of mis detections and false alarms associated with conventional energy detector, we proposed an enhancement to this by way of considering the statistics of recent past detections. This proposed enhanced spectrum sensing algorithm is reported in [T4].

2. ***Spectrum Decision*:** Once the detection of vacant channels is complete, one may locate more than one channel to be available. Then which of the channels is to be deployed is addressed by this component. The selection of the best from among the detected channels is carried out based on parameters such as channel capacity, channel holding time and SU location [18], so as to provide the best QoS to the secondary user. The proposed QoS approaches are as in [19] and the prime concern is to address:

    i. Minimizing channel selection overloads

    ii. Optimizing channel selection

    iii. Enabling of modelling SUs activity

    In the current work, we proposed a system model which first calculates the feasible relays for reliable transmission of data to improve the QoS and the results were reported in [T7].

3. ***Spectrum Sharing*:** Spectrum underutilization problem can be handled by dynamic spectrum access/opportunistic spectrum access and spectrum sharing [20]. In dynamic spectrum access whenever PU is not utilizing the band then cognitive user can make use

of it until PU arrives. In spectrum sharing both PU and SU can transmit simultaneously with power constraints on SU transmitter.

In the current work, we proposed a power optimization method which helps in simultaneous transmission of primary user and secondary user data without causing any interference to primary user to improve the QoS and the results were reported in [T1].

4. ***Spectrum Mobility*****:** Once the spectrum is allocated to the SU and if PU comes back during data transmission the secondary user has to vacate and find the other band to complete its communication. Spectrum mobility [21] plays an important role to avoid interference to PU. Spectrum mobility can happen in two types, reactive and proactive. In reactive spectrum mobility, continuous sensing/monitoring of PU activity is done and based on the result cognitive user will switch its communication. In proactive spectrum mobility, based on the pre available spectrum information about PU, PU's emergence is predicted and CU will switch its communication.

In the current work, we have worked on both reactive and proactive spectrum mobility techniques. Both of them perform well but in reactive the continuous monitoring is performed hence more resources are required compared to proactive which has past spectrum information with it. Both the methods helped in improving the QoS and the results were reported in [T1], [T2].

1.6 Objective of the Thesis

The main objective of the thesis is to study the issues in QoS enhancement in Cognitive Radio based Networks so as to enable building of robust CR based networks. Towards to achieving this objective we focused on the following:

- To enhance the spectrum sensing algorithm for better Qos in Cognitive radio networks
- To apply this method to cognitive radio network and validate the results by applying enhanced spectrum sensing on spectrum analyzer
- To calculate the route sustenance time and connection sustenance time which are very important parameters for improving the Qos of a Cognitive radio network
- To further enhance the Qos of cognitive network architecture by using combination of enhanced spectrum sensing and hybrid spectrum sensing for joint interweave and overlay model.
- To apply the proposed algorithms and enhancing them for cognitive radio enabled IoT (Internet of Things) network.

1.7 Thesis Organization

The thesis is organized as follows. Chapter 2 discusses about spectrum sensing algorithms and enhancing the conventional spectrum sensing method. For the purpose of validation the proposed algorithm is applied on spectrum analyser and results are presented. In the third chapter analysis about route sustenance time and connection sustenance time are done, which are very important parameters in improving Qos of cognitive radio networks. These two parameters are tested on vehicular and pedestrian traffics and results are presented. In chapter 4 a joint interweave underlay mode is presented with the help of proposed Enhanced spectrum sensing and Hybrid spectrum sharing. In this chapter the focus is on power optimization based on the PU sensing result. In chapter 5 proposed algorithms are applied on cognitive radio enabled IoT network. In this chapter spectrum quality and spectrum availability are estimated based on two parameters called global information about spectrum usage and instant spectrum status information. Chapter 6 gives conclusions and directions for future work.