EFFICIENT DETECTION SCHEMES FOR COOPERATIVE SPECTRUM SENSING IN FADING CHANNELS USING COGNITIVE RADIO NETWORKS

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ABSTRACT

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Advancements in wireless technologies are a breakthrough in revolutionizing the communication paradigm by providing ubiquitous internetwork access to large number of users at incredibly high data rates. The ever increasing deployment of mobile applications, networks and diverse services are a true depiction to this fact. As this trend continues the phenomenon of frequency spectrum occupancy is mounting up leading to spectrum scarcity. Analysis shows that for most periods the spectrum in control of majority primary users remains vacant and underutilized. This eventually implied to the idea of Dynamic spectrum allocation to users by Federal Communication Commission (FCC) which worked as a preventive measure against the issue of spectrum scarcity and underutilization.

Cognitive Radios are sophisticated devices which can effectively sense the availability of frequency bands and can self modulate its parameters for dynamic transmission. In this thesis we have focused on Primary transmission detection techniques for spectrum sensing. Comprehensive analysis of energy detection, matched filter detection and cyclostationary feature detection is done with prime emphasis on their advantages and limitations. Based on these results we have proposed a two-step detection scheme which outperforms the existing models in terms of detection probability even at very low SNR value. The censoring capability of this detector leads to energy efficiency in cooperative environment. Analysis is done on Nakagami channel model for wireless communication which includes fading and multipath propagation effects. The system model discussed

provides good agility for band shifting in case of interference or primary user presence because of reasonable sensing time which is very close to that of cyclostationary feature detector and can differentiate between desired signal and wideband noise.

I would like to dedicate this thesis to my parents, family and wider community of teaching faculty whose efforts really paved a great deal to serve the humanity with knowledge at large.

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Chapter 1

Introduction

1.1 Motivation and Objectives

Technology breakthrough is immense in wireless networks out of which cognitive radios also possess a big share. The thesis under consideration confers some major glitches in this domain, one of which is spectrum sensing. Our intention is to bring forward enhanced detection method for spectrum sensing that outpaces the conventional schemes in critical considerations like detection sensitivity and estimation of average detection time.

Objective of this research is to study

a. Energy Detection under various scenarios and regimes.
b. Impact of wireless fading channels on Detection performance and studying Nakagami channel distribution as an example.
c. Developing a two-stage detection technique which at first stage performs crude detection using primitive energy detectors and do fine tuning in the second stage using Cyclostationary Detectors.
d. Simulation results relating Performance of Primary Transmitter Detectors and two- step Detector in Nakagami fading channels.

1.1.1 Cognitive Radio Networks

The advent of Wireless technology in current Communication Systems is drastic and revolutionary as millions of devices using a panorama of sophisticated techniques are deployed wide across the world. With every coming day the demand of high speed wireless network access is increasing in virtually all major applications covering voice, multimedia and real time data with a provisional addition of very low delay requirements.

In the light of this emergent regime and severe competition going on, we are also faced with an acute problem of radio spectrum scarcity. To tackle this all Federal Communication Commission (FCC) Spectrum Policy Task Force made a decisive move of making a paradigm shift by allowing the potential unlicensed users to transmit data in the frequency slot thereby increasing the efficiency of available spectrum resource. The annual report published by FCC in May 2004 signifies the initiative of permitting the secondary users (those who do not have a license to use the spectrum space) to opportunistically use the vacant slots in the television spectrum. The ATSC DTV system requires a usual bandwidth of 6 MHz. Transmission and operating range of wireless radio access networks (WRAN) systems; involve another Primary Unit which utilizes a 200 kHz spectrum bandwidth. Strict limitations and rules enforcement on operators and manufacturers is done by the radio spectrum regulatory bodies. This command and control nature of regulations limits the access of radio resource which notions a concern more vital then the actual spectrum dearth in temporal and geographical dimensions [2]. Though, these secondary users should not create interference to the licensed user, when the licensed user wants to utilize the spectrum band the unlicensed user should immediately vacate the spectrum and should look for some other free space. All these operation require high degree of sensing and precision which is achieved by introduction of Cognitive Radios in the network. Location demographics show that even in city and large urban areas, at many quarters of time the communication spectrum is vacant or partially utilized. Therefore Cognitive Units need to perform additional tasks the a presumed normal wireless user. The detection of spectrum holes (spectrum sensing) with sufficient reliability is one such major task to perform by Cognitive Units. [2].

1.1.2 Spectrum Sensing

Spectrum sensing involves the detection of the primary user transmissions on a preassigned frequency band. This reconnaissance of Primary transmitter in the frequency band under observation is of prime importance as it provides an estimate of level of spectrum usage. If currently the band is not in use then in this case it may be assigned to some other user for a defined duration of time. Literature broadly describes three main techniques for spectrum sensing: cooperative detection, primary transmitter detection and interference based detection. The focus of our work is on the analysis of an important class of spectrum sensing methods known as the transmitter detection. Generally transmitter detection includes three techniques: Energy Detection, Matched Filter Detectors and Cyclostationary Detectors. Energy Detectors outcast all the mentioned techniques due to its simple implementation scheme, ability to distinguish any waveform shape and inbuilt confidentiality observance offered to the primary communication.

1.1.3 Methods to Sense existence of Primary Users

Understanding the significance of Primary User detection different techniques can be proposed at various levels of data communication layer stack. Investigation of the capabilities and constraints of such techniques from the viewpoint of optimizing a given network of interest is usually of prime importance .We need to understand fundamental performance limitations of these techniques in addition to the knowledge of operative information of existing cognitive radio software and hardware platforms. In literature several scopes for designing primary transmitter detection procedures in cognitive radio networks, which include sensing of Transmitter or receiver units, and collaborative and non-collaborative detection is explored. [1] The three primary detection techniques discussed in the current thesis include

a. Energy Detection

b. Detections using Matched Filter Scheme

c. Cyclostationary Feature Detection

Analysis shows that Energy Detection Technique is simple to implement because the receiver work without using any previous channel and signal information to detect a primary unit. This technique is used where the receiver does not have much information about the primary user and only the value of white Gaussian noise is known. In matched filter detection, as compared to energy detection technique, a linear filter is used that maximizes the Signal to Noise Ratio. This filter makes use of the correlation phenomenon in which process of convolution is applied to unknown signal with impulse response as reference by inverting and time shifting it on the same scale. Input signal gets screened by a band pass filter which estimates the energy in the desired band, and then the output of this filter is processed using mathematical convolution with the technique of matched filter whose generated impulse response is the desired signal. This sets a threshold to search the existence of a licensed user. In addition to this all, Cyclostationary Feature Detection is a still a much optimized technique that can easily isolate the noise from the user signal. In Cyclostationary Feature Detection technique, Cognitive Radio can distinguish between noise and user signal on basis of its periodicity. In Cyclostationary Feature Detection, modulated signals (transmitted signal) which carry information are usually sine waves; pulse trains i.e. have same periodic properties in it. The name cyclostationary derives its origin from the fact that mean and autocorrelation characteristics of such signals are periodic. Spectral correlation function (SCF) is the method to estimate the properties of signals as to how far it fulfills the condition of being periodic. SCF can distinguish between the noise energy and the modulated signal energy because according to stochastic theory noise is wide-sense stationary (WSS) signal which demonstrate no periodic traits. Cyclostationary detection can perform better than energy detection and matched filter detection because it has the ability to distinguish between noise and signal.

1.2 Problem Statement

Wireless channels predominantly have fast fading characteristics which can affect the detection capabilities of devices. Quantification of these parameters is required so that system analyzers can employ remedial measures to combat the degenerative effect in the scheme. The biggest hurdle faced is the SNR (Signal to Noise ratio) constraint in which SNR below a certain threshold is not permissible. These threshold levels are of prime importance in judging the behavior of different fading models [5]. In Nakagami-m fading model the mathematical expression for SNR is limited to integral form [6]. Classification of the efficiency of mentioned detectors and evaluating their effectiveness in different fading channels we need to look into the close form expressions on SNR with different parameters [7]. Rayleigh and Rician fading models are the most celebrated models in wireless research regime but still they don't incorporate some experimental data and parameters. Thus we need to investigate on a more general and comprehensive fading distribution which can accommodate a variety of pragmatic situations [8]. The model which evolves is called Nakagami Distribution. Gamma function of this distribution is represented as

$$f\,(\boldsymbol{\gamma}) = \frac{\mathbf{1}}{(\boldsymbol{m})}\left(\frac{\boldsymbol{m}}{}\right)^{\boldsymbol{m}} \boldsymbol{\Upsilon}^{\boldsymbol{m-1}}\,\boldsymbol{exp}\left(-\frac{\boldsymbol{m\Upsilon}}{}\right)\,, \boldsymbol{m} \geq \mathbf{0}.5 \qquad (1.1)$$

Sensing of a Frequency band at conditions of low SNR is an issue of prime focus. As far as energy detectors are concerned they are responsive to noise uncertainty. Hence they are not effective to be used at low Signal to Noise ratio levels.

1.3 Proposed Solution

We worked on a two-step methodology to sense the transmitting unit which consists of crude and a tuned sensing. Crude sensing locates vacant frequency bands in the spectrum by using energy detector and later in the tuned sensing step; Cyclostationary Detector comes into action giving details of the level of channel usage to make a final decision. Graphs from simulations indicate that a particular noise level , two-step methodology beats the performance of both Energy and Cyclostationary Detector in regards to metrics like channel sensing and average time for detection In the condition when the random noise level in channel increase leading to decreased SNR range proposed methodology outperforms both the primitive detectors.

1.4 Scope and Limitations

The scope of the analysis is subjected to following assumptions and limitations.

a. Wireless channel is modeled as quasi static.
b. Transmitter and receiver is assumed to be in perfect channel state information (CSI).
c. The provision of a feedback channel is provided between transmitter and receiver units to exchange information.
d. Feedback channel is also available between primary users and cognitive users in direct or indirect mode.

1.5 Contribution to Field

In this thesis research, the problem of spectrum sensing is investigated with application to cognitive radio networks. Our system model is developed based on the energy detector. We presented a comparative analysis of energy detector performance variation over three different fast fading channel models; namely, Nakagami-m, Rician and Rayleigh. Study is carried out in depth, to look into the mathematical complexities involved while dealing integrals of Marcum-Q function with the Probability Density Function (PDF) based technique, alternative series representations, approximation models such as Torreri’s model, Edell model and Berkeley’s model. Further we escalated the approach in Edell’s model to devise an approximate model for refined and concise calculations for Probability of detection $P_{d,Nak}$ for Nakagami Fading channels. Simulations have been carried out which verify the closeness of approximate models with theoretical ones.