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Energy Based Spectrum Sensing in Cognitive Radio Networks

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ABSTRACT

Cognitive radio (CR) can successfully deal with the growing demand and scarcity of the wireless spectrum. To exploit limited spectrum efficiently, CR technology allows unlicensed users to access licensed spectrum bands. Since licensed users have priorities to use the bands, the unlicensed users need to continuously monitor the licensed user's activities to avoid interference and collisions. How to obtain reliable results of the licensed user's activities is the main task for spectrum sensing. This work will mainly focus on the spectrum sensing based on energy detection algorithm.

Introduction

In the past ten years, we have witnessed a dramatic growth in wireless communication due to the popularity of smart phones and other mobile devices. As a result, the demand for commercial spectrum has been skyrocketing. For instance, AT&T projects a 5000% increase in data usage in the next three years, Yankee Group predicts 29-fold increase in US mobile data traffic from 2009 to 2015, and CTIA estimates that U.S. cellular companies need at least 800MHz more spectrum over the next 6 years. Clearly limited spectrum is a crucial impediment to continued growth of commercial wireless services. Similarly, we are seeing increasing demand for unlicensed bandwidth, due to the continuing growth of as WiFi, and emergence of application domains, such as sensor networks for safety applications, home automation, smart grid control, medical wearable and embedded wireless devices, and entertainment systems.

Meeting this huge demand for bandwidth is a challenge since most easily usable spectrum bands have been allocated. Many studies have however shown that more than 90% of the allocated spectrum is unused or underutilized. This suggests that meeting future demands for wireless bandwidth will not only require new communication and networking technologies that use the spectrum more efficiently (i.e. increase bits/second/Hz), but also new techniques for increasing spectrum utilization. Today's spectrum policy relies largely on static spectrum allocation, which is simple and encourages investments in infrastructure. However, it does mean that many of the frequency bands are only used in certain areas and/or part of the time. A different approach, called Dynamic Spectrum Access (DSA), allocates spectrum more dynamically and it is an active area of research. DSA requires not only advances in technology but also new policy and economic models for spectrum use.

Cognitive radios are widely viewed as the disruptive technology that can radically improve both spectrum efficiency and utilization. Cognitive radios are fully programmable wireless devices that can sense their environment and dynamically adapt their transmission waveform, channel access method, spectrum use, and networking protocols as needed for good network and application performance. One of the applications of cognitive radio is more efficient, flexible, and aggressive dynamic spectrum access. The research community has made significant progress in addressing the many research challenges associated with cognitive networks and DSA. However, there is a big gap between individual research results, effectively building blocks, and the large-scale deployment of cognitive networks that dynamically optimize spectrum use. *Bridging this gap is one of the major research challenges we identified in the workshop.* Recent developments such as the FCC TV white space ruling, an example of DSA based on a primary-secondary user model, and LTE-A, which relies on flexible spectrum use, offer great opportunities to demonstrate the potential value of cognitive networks and DSA. Failure to act on these opportunities could delay commercial deployment for many years.

This breakout session brought together technology and policy researchers to explore how we can realize the great potential and commercial success of cognitive networks and DSA. Specifically, we tried to identify both long-term research challenges and near term research opportunities.

Research Challenges

With the exception of unlicensed spectrum which tend to be more heterogeneous, most spectrum bands are used in a fairly homogeneous fashion, i.e. the network uses a single (or close related) technology and it is designed by a single organization. In contrast, cognitive networks are inherently heterogeneous. This fundamental difference raises many significant challenges, as identified in a recent NSF-sponsored workshop on "Future Directions in Cognitive Radio Network Research" [CRN1]:

- Spectrum policy alternatives and system models
- Spectrum sensing
- Cognitive radio architecture, software abstraction
- Cooperative communications and networking
- DSA technology and algorithms
- Protocol architectures for cognitive networks
- Cognitive algorithms for adaptation, resource management
- Network security for cognitive network
- Cognitive networks and the Internet

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Related Work

In Future wireless applications there are a great demand for high data rates and large capacity. Spectrum has become a scarce and expensive resource because Bandwidth is very limited Due to the rapid growth of wireless communications, more and more spectrum resources are needed in future to drive more users. To achieve high data rates and large capacity for future demand the possible solution is effective usage of existing spectrum.CR is a technology that helps users to use spectrum effectively.

The Federal Communications Commission (FCC) is responsible for regulation of interstate telecommunication, management and licensing of electromagnetic spectrum within the United States and it enforces requirements on inter station interference in all radio frequency bands. They license segments to particular user's in particular geographic areas. A few, small, unlicensed bands were left open for anyone to use as long as they followed certain power regulations. With the recent boom in personal wireless technologies, these unlicensed bands have become crowded with everything from wireless networks to digital cordless phones. To combat the overcrowding, the FCC has been investigating new ways to manage RF resources. The basic idea is to let people use licensed frequencies, provided they can guarantee interference perceived by the primary license holders will be minimal. With advances in software and cognitive radio, practical ways of doing this are on the horizon. Cognitive Radio can smartly senses and adapts with the changing environment by altering its transmitting parameters, such as modulation, frequency, frame format etc. In the early days of communication there were fixed radios in which the transmitter parameters were fixed and set up by their operators. The new era of communication includes Software Defined Radio (SDR). A SDR is a radio that includes a transmitter in which the operating parameters including the frequency range, modulation type or maximum radiated or conducted output power can be altered by making a change in software without making any hardware changes .SDR is used to minimize hardware requirements; it gives user a cheaper and reliable solution. But it will not take into account spectrum availability. Cognitive Radio (CR) is newer version of SDR in which all the transmitter parameters change like SDR but it will also change the parameters according to the spectrum availability. In the authors measure the power spectral density (PSD) of the received 6 GHz wide signal. Figure 1. shows very low utilization of spectrum from 3-6 GHz. In order to improve spectrum efficiency dynamic spectrum access technique is imperative.

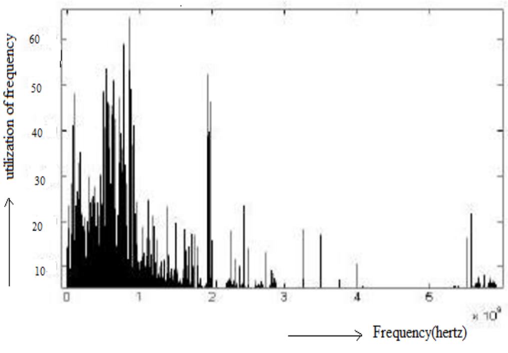


Figure 1. Measurement of 0-6 GHz spectrum utilization at BWRC.

Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. More specifically the cognitive radio technology will enable the user to determine which portion of the spectrum is available, detect the presence of primary user (spectrum sensing), select the best available channel (spectrum management), coordinates the access to the channel with other users (spectrum sharing) and migrate to some other channel whenever the primary user is detected (spectrum mobility).

Characteristics of Cognitive Radios

Cognitive radio dynamically selects the frequency of operation and also dynamically adjusts its transmitter parameters. The main characteristics of cognitive radios are **Cognitive Capabilities and Reconfigurability.**

Cognitive Capability

Cognitive capability refers to the ability of radio to sniff or sense information from its environment and perform real time interaction with it. The cognitive capability can be explained with the help of three characteristics; Spectrum Sensing, Spectrum Analysis and Spectrum Decision. The spectrum sensing performs the task of monitoring and detection of spectrum holes. The spectrum analysis will estimate the characteristic of detected spectrum hole. In the spectrum decision, the appropriate spectrum is selected by determine the parameters like data rate, transmission mode etc.

Reconfigurability

Reconfigurability refers to the ability of radio that allows the cognitive radio to adjust its parameters like link, operating frequency, modulation and transmission power at run time without any modifications in the hardware components. In other words Reconfigurability of CR is SDR. Doing so we dynamically change all the layers of communication as shown in Figure 2. We can use different technologies depending on their spectrum availability with the same hardware.

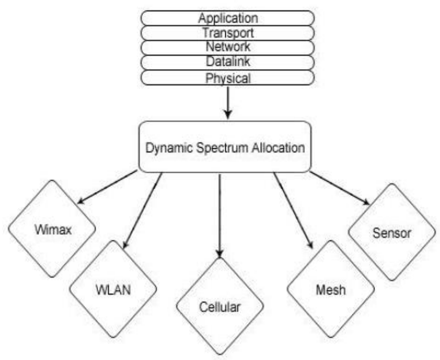


Figure 2. Dynamic changes in all layers.

The Cognitive Radio Architecture

Existing wireless network architectures employ heterogeneity in terms of both spectrum policies and communication technologies. Moreover, some portion of the radio spectrum is licensed for different technologies and some bands remain unlicensed (called Industrial Scientific Medical (ISM) band). A clear description of Cognitive Radio Network architecture is essential for the development of communication protocols. The components of the Cognitive Radio network architecture, as shown in Figure.3, can be classified in two groups such as the primary network and the CR network. The basic elements of the primary and the CR network are defined as follows

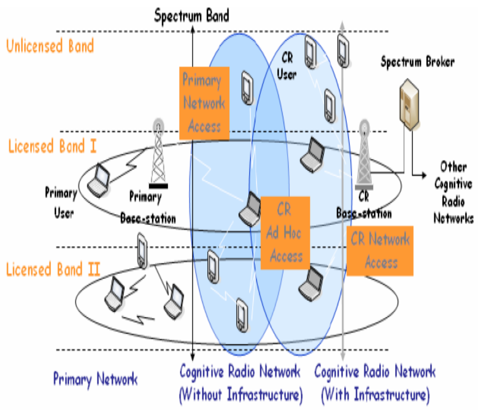


Figure 3. Cognitive Radio Network Architecture

Primary network

A network with rights for a specific radio spectrum band is called primary network. Examples include the common cellular network, WiMAX, CDMA and TV broadcast networks. The components of the primary network are as follows.

Primary user

A user of primary network which has a license to operate in a certain spectrum band. Primary user has access to the network via base-station. All of its services and operations are controlled by base-station. Hence, it should not be affected by any unlicensed user or user of any other network. Therefore, primary users do not need any change for coexistence with Cognitive Radio base-stations and Cognitive Radio users.

Primary base-station

A fixed infrastructure network component for a specific technology with licensed band is called Primary base-station. Examples are base-station transceiver system (BTS) in a cellular system and BTS in WiMAX etc. Primary base-station does not have capability for coexisting with Cognitive Radio Network, hence, the primary base-station require some modifications such as the need to have both licensed and Cognitive Radio protocols present for the primary network access of CR users.

Cognitive Radio network

A network where the spectrum access is allowed only in opportunistic manner and does not have license to operate in a desired band is called Cognitive Radio Network. It can be deployed both as an infrastructure network and an ad hoc network as shown in Figure 3. The components of a CR network are as follows.

Cognitive Radio user

Cognitive Radio user or secondary user has no spectrum license for its operation so some additional functionality is required to share the licensed spectrum band.

Cognitive Radio base-station

Cognitive radio base-station or secondary base-station is a fixed infrastructure component that provides single hop connection to Cognitive Radio users without any license of radio spectrum. Cognitive Radio user can access the other networks with the help of this connection.

Spectrum broker

Spectrum broker is a central network entity that provides the sharing of spectrum resources among different CR networks. Hence, spectrum broker can be connected to each network like star topology in Networks and can act as centralized server having all information about spectrum resources to enable coexistence of multiple CR networks.

Problem Statement

The main objective is to detect and classify the spectrum sensing techniques for cognitive radio networks by using signal processing techniques. The sensing has been analyzed for a few identified situations and then these behaviors have been reported to the operator for further action.

Objectives

The primary objective of this paper is to conduct a comprehensive appraisal of the contemporary techniques used for spectrum sensing in cognitive radio networks and to provide implementation of suitable techniques. The secondary objective includes identification of the areas for improvement of the results and the resolution of the identified deficiencies.

Classification of Spectrum Sensing

The main challenge to the Cognitive radios is the spectrum sensing. In spectrum sensing there is a need to find spectrum holes in the radio environment for CR users. However it is difficult for CR to have a direct measurement of channel between primary transmitter and receiver.

A CR cannot transmit and detect the radio environment simultaneously, thus, we need such spectrum sensing techniques that take less time for sensing the radio environment. In literature the spectrum sensing techniques have been classified in the following three categories.

A cognitive radio senses the radio environment. Finds available spectrum band, the information related to its parameters and detects spectrum holes.

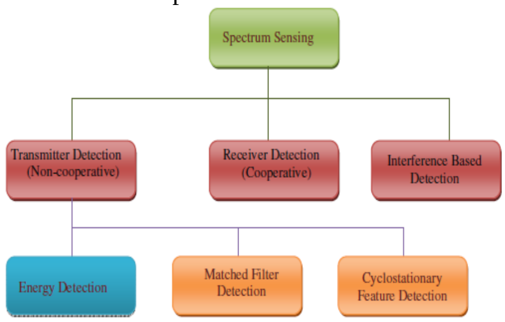


Figure 4. Classification of Spectrum sensing

Implemented Method

Energy Detection Method

Energy detection (also denoted as non-coherent detection), is the signal detection mechanism using an energy detector (also known as radiometer) to specify the presence or absence of signal in the band. The most often used approaches in the energy detection are based on the Neyman-Pearson (NP) lemma. The NP lemma criterion increases the probability of detection(P_d) for a given probability of false alarm(Pf_a). It is an essential and a common approach to spectrum sensing since it has moderate computational complexities, and can be implemented in both time domain and frequency domain. To adjust the threshold of detection, energy detector requires knowledge of the power of noise in the band to be sensed. Compared with energy detection, matched filter detection and cyclostationary detection require a priori information of the PUs to operate efficiently, which is hard to realize practically since PUs differ in different situation. Energy detection is not optimal but simple to implement, so it is widely adopted. The signal is detected by comparing the output of energy detector with threshold which depends on the noise floor.

In this technique there is no need of prior knowledge of Primary signal energy.

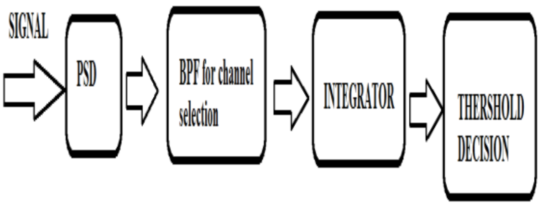


Figure 5 Block Diagram of Energy Detection

The block diagram for the energy detection technique is shown in the Figure 5. In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions .

$y(k) = n(k)$…………… H0 (absence of user)

$y(k) = h * s(k) + n(k)$…… H1 (presence of user)

Where y (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance σ^2. Let y(k) be a sequence of received samples $k\epsilon\{1, 2….N\}$ at the signal detector, then a decision rule can be stated as, H0

H0…… if $\varepsilon > v$

H1…… if $\varepsilon < v$

Where $\varepsilon = E\,|y(k)|^2$ the estimated energy of the received signal and v is chosen to be the noise variance σ^2.

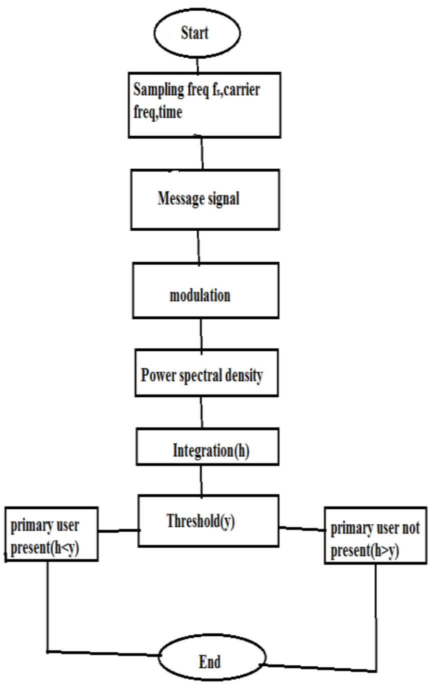
However Energy Detection is always accompanied by a number of disadvantages

i) Sensing time taken to achieve a given probability of detection may be high.

ii) Detection performance is subject to the uncertainty of noise power.

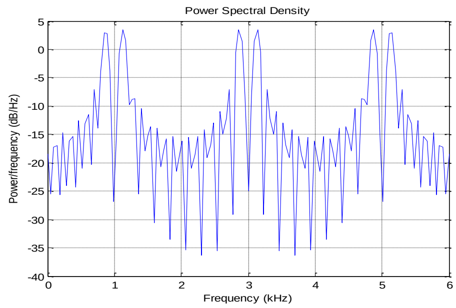
iii) Energy Detection cannot be used to detect spread spectrum signals.

FLOW CHART

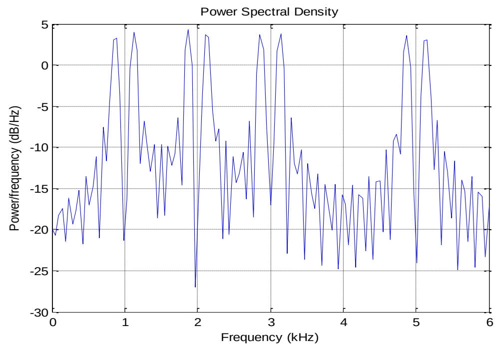


SIMULATION RESULTS

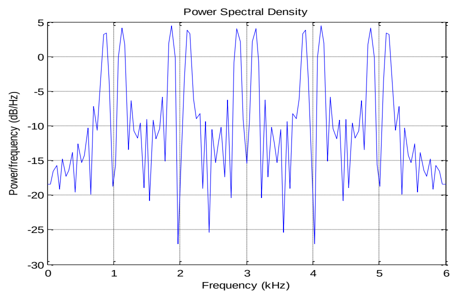
Do you want to enter first primary user Y/N: y
Do you want to enter second primary user Y/N: n
Do you want to enter third primary user Y/N: y
Do you want to enter fourth primary user Y/N: n
Do you want to enter fifth primary user Y/N: y



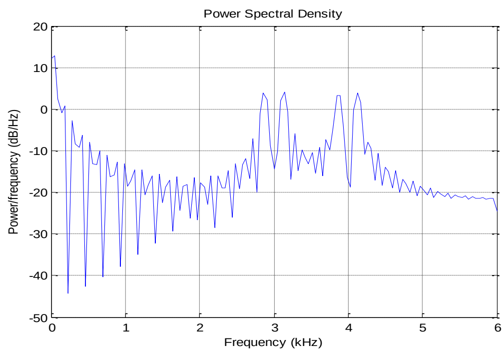
Do you want to enter a secondary user Y/N: y
Assigned to User 2 as it was not present.
Do you want to re-run the program? [Y/N]: Y



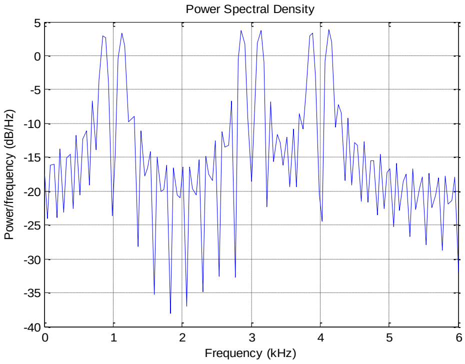
Do you want to enter a secondary user Y/N: y
Assigned to User 4 as it was not present.
Do you want to re-run the program? [Y/N]: n



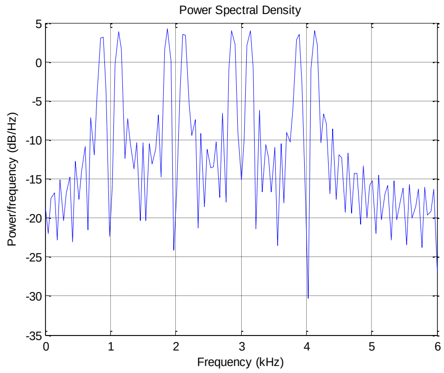
Do you want to enter first primary user Y/N: n
Do you want to enter second primary user Y/N: n
Do you want to enter third primary user Y/N: y
Do you want to enter fourth primary user Y/N: y
Do you want to enter fifth primary user Y/N: n



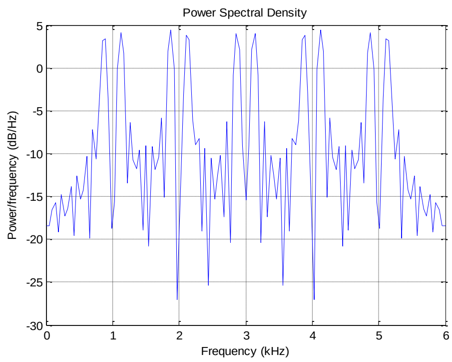
Do you want to enter a secondary user Y/N: y
Assigned to User 1 as it was not present.
Do you want to re-run the program? [Y/N]: y



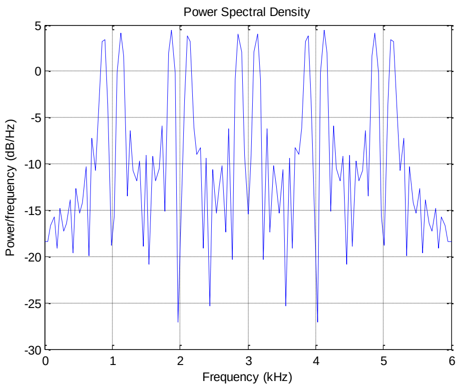
Do you want to enter a secondary user Y/N: y
Assigned to User 2 as it was not present.
Do you want to re-run the program? [Y/N]: y



Do you want to enter a secondary user Y/N: y
Assigned to User 5 as it was not present.
Do you want to re-run the program? [Y/N]: n



Do you want to enter first primary user Y/N: y
Do you want to enter second primary user Y/N: y
Do you want to enter third primary user Y/N: y
Do you want to enter fourth primary user Y/N: y
Do you want to enter fifth primary user Y/N: y



Do you want to enter a secondary user Y/N: y
all user slots in use. try again later,

Do you want to re-run the program? [Y/N]: n

Conclusion

If CR can't have sufficient information about primary user's waveform, then the matched filter is not the optimal choice. However if it is aware of the power of the random Gaussian noise, then energy detector is optimal.

The advantage's of Energy Detection method is does not need any prior information and low computational cost.

One of the main problems of energy detection is that performance is susceptible to uncertainty in noise power. It cannot differentiate between signal power and noise power rather it just tells us about absence or presence of the primary user.

Knowing some of cyclic characteristics of signal one can construct detectors that signal are its statistics like mean and autocorrelation. Periodicity is commonly embedded in sinusoidal carriers, pulse train, spreading code, hoping sequences ,cyclic prefixes of primary signals. The cyclic correlation function is used for detecting signals present in the spectrum.SNR ratio will increase in cyclostationary feature detection method.

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