Review on Spectrum Sensing Techniques and Algorithms for Cognitive Radio Applications

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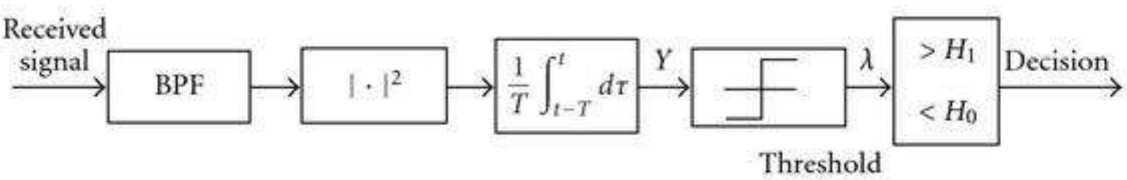
Abstract— **Spectrum sensing is an essential and sensitive task in cognitive radio since interfering with another user is prohibited. Detecting the presence of the primary users as fast as possible is main requirement. The spectrum sensing problem has gained new aspects with cognitive radio and opportunistic spectrum access concepts. It is prime challenging issue in cognitive radio systems. The main objective of this paper is to present various spectrum sensing techniques used in cognitive radio to allow access to the secondary user when the main user not utilizing band of frequency at that time. Brief survey of spectrum sensing methodologies for cognitive radio presented.**

Index Terms— **cognitive radio, spectrum sensing, cooperative sensing, primary user, secondary user**

I. Introduction

Innovative techniques that can offer new traditions of exploiting the available spectrum are needed because the necessity for higher data rates is increasing as a result of the transition from voice-only communications to multimedia type applications. From limited range of spectrum, the identification of way for occupying the increasing demand of bandwidth has given rise to a new technology known as Cognitive Radio. One important component of the cognitive radio concept is the ability to measure, sense and be aware of the parameters linked to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications. A cognitive radio network consists of set of secondary radio users that can execute spectrum sensing and then operate at the appropriate portion of unused spectrum. The radio measures certain characteristics of the radio waveform, and then decides if a primary system is actively using that spectrum. General structure of energy detector as follows.

Figure 1: General structure of Energy Detector



In cognitive radio terminology, *primary users* can be defined as the users who have higher priority on the usage of a specific part of the spectrum. On the other hand, *secondary users*, who are having lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum. Spectrum sensing is the task of obtaining awareness about the spectrum usage and existence of primary users in a geographical area. This awareness can be obtained by using geolocation and database, by using beacons, or by local spectrum sensing at cognitive radios. Spectrum sensing is essential and responsive task in cognitive radio since interfering with other users is illegal. Cognitive radio offering interesting solution to spectral crowding problem by launching the opportunistic usage of frequency bands that are not occupied by licensed users. Various aspects of the spectrum sensing task are illustrated in following table.

Table 1: Few aspects of spectrum sensing for cognitive radio

Level 1	**Spectrum sensing**			
Level 2	**Enabling algorithms**	**cooperative sensing**	**challenges**	**Approaches**
Level 3	Energy detection	Device-centric(local)	Hardware requirement	internal sensing
	Matched filtering	Centralized sensing	Spread spectrum users	external sensing
	Waveform based sensing	External sensing	Security	Location based sensing
	Radio identification based sensing	Distributed sensing	Hidden primary user problem	

In the level 2 the division of spectrum sensing methodologies represented and in the level 3 the corresponding subdivision is represented column wise.

II. COGNITIVE TASKS

A cognitive radio looks logically to software- defined radio to perform cognitive task. For the other tasks, the cognitive radio looks to signal-processing and machine-learning procedures for the implementation. The cognitive process begins with the passive sensing of RF spur and terminate with action.

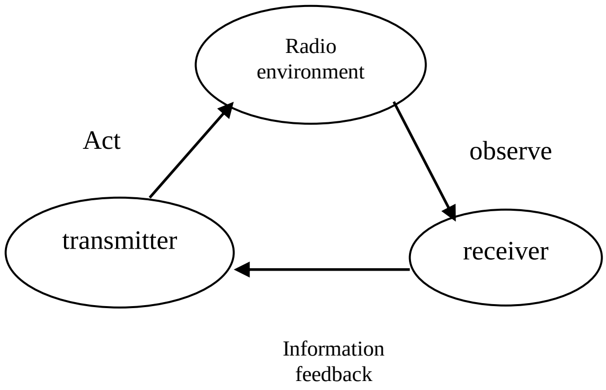
The working procedure and subtasks are as follows: Tasks 1 and 2 are carried out in the receiver, and the task 3 is carried out in the transmitter.

1) Radio-scene analysis:
- Calculation of interference temperature of the radio environment;
- Detection of spectrum holes.

2) Channel identification:
- Estimation of channel-state information (CSI)
- Estimation of channel capacity for use by the transmitter

3) Transmitter-power control and the dynamic spectrum management.

Figure 2: Basic Cognitive Cycle



It is clear that the cognitive module in the transmitter must work in a harmonious manner with the cognitive modules in the receiver. In order to maintain this harmony between the cognitive radio's transmitter and received at all times, there is a need of a feedback channel connecting the receiver to the transmitter. Through the feedback channel, the receiver is enabled to convey information on the performance of the forward link to the transmitter. So, cognitive radio is an example of a feedback communication system.

III. OTHER DIMENSIONAL SPECTRUM AWARENESS

The conventional definition of the spectrum opportunity, which is often defined as "*a band of frequencies that are not being used by the primary user of that band at a particular time in a particular geographic area*" , only exploits three dimensions of the spectrum space: frequency, time, and space. Conventional sensing methods usually relate to sensing the spectrum in these three dimensions. However, there are other dimensions that need to be explored further for spectrum opportunity.

Table 2: OTHER DIMENSIONAL RADIO SPECTRUM SPACE AND TRANSMISSION OPPORTUNITIES

s.no.	Sensing mechanism	suitable parameter	Method
1	In the frequency domain	Frequency	The available spectrum is divided into narrower bands. Spectrum opportunity in this dimension means that all the bands are not used at the same time.
2	In a specific band w.r.t. time.	Time	The band is not continuously used. There will be times where it will be available for opportunistic usage.

3	Location based(latitude, longitude, and elevation) and distance of primary user.	Geographical space	This takes advantage of the propagation loss (path loss) in space. These measurements can be avoided by simply looking at the interference level. No interference means no primary user transmission in a local area.
4	The spreading code, time and frequency hopping sequences used by the primary users	Code	Simultaneous transmission without interfering with primary users would be possible in code domain with an orthogonal code with respect to codes that primary users are using.
5	Directions of primary users' beam	Angle	If a primary user is transmitting in a specific direction, the secondary user can transmit in other directions without creating interference on the primary user.

IV. DIFFICULTIES FACED IN SENSING PROCESS

A. Hardware Requirements

Spectrum sensing for cognitive radio applications requires high sampling rate, high resolution analog to digital converters (ADCs) with large dynamic range.

Table 3: Comparison of Algorithms

	Drawback	Advantage
Single -Radio	Poor accuracy, low efficiency	simple and with lower cost
Double-Radio	Higher in cost and complexity	Efficient and with better accuracy

B. Concealed Primary User Problem

The concealed primary user problem can be caused by many factors including severe multipath fading or shadowing observed by secondary users while scanning for primary users' transmissions. Cognitive radio device causes unwanted interference to the primary user (receiver) as the primary transmitter's signal could not be detected because of the locations of devices.

C. Sensing period and Frequency

Primary users can claim their frequency bands anytime while cognitive radio is operating on their bands. In order to prevent interference to and from primary license owners, cognitive radio should be able to identify the presence of primary users as quickly as possible and should vacate the band immediately. Hence, sensing methods should be able to identify the presence of primary users within a certain duration. This requirement poses a limit on the performance of sensing algorithm and creates a challenge for cognitive radio design.

D. Safety

In cognitive radio, a selfish user can modify its air interface to mimic a primary user. Hence, it can mislead the spectrum sensing performed by legitimate primary users. Such a behavior or attack is investigated in and it is termed as primary user emulation (PUE) attack.

V. VARIOUS SENSING METHODS

A. Energy Detector Based Sensing

Energy detector based approach, also known as periodogram, is the most common way of spectrum sensing because of its low computational and implementation complexities. In addition, it is more generic as receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold . Some of the challenges with energy detector based sensing include selection of the threshold for detecting primary users, inability to differentiate interference from primary users.

B. Waveform-Based Sensing

Patterns like preamble is a known sequence transmitted before each burst and a midamble is transmitted in the middle of a burst or slot. In the presence of a known pattern, sensing can be performed by correlating the received signal with a known copy of itself. This method is only applicable to systems with known signal patterns, and it is termed also as coherent sensing. it was shown that the performance of the sensing algorithm increases as the length of the known signal pattern increases.

C. Cyclostationarity-Based Sensing

Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing. Instead of power spectral density (PSD), cyclic correlation function is used for detecting signals present in a given spectrum. The cyclostationarity based detection algorithms can differentiate noise from primary users' signals.

D. Radio Identification Based Sensing

A complete knowledge about the spectrum characteristics can be obtained by identifying the transmission technologies used by primary users. Such an identification enables cognitive radio with a higher dimensional knowledge as well as providing higher accuracy

E. Matched-Filtering

Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known .The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of misdetection as compared to other methods.

Table4: Comparison of sensing methods

s.no.	Accuracy wise (Low to High)	Complexity wise (Low to High)
1	Energy detector	Energy detection
2	Cyclostationary	Waveform-based
3	Radio identification	Cyclostationary
4	Waveform-based and Matched filtering	Radio identification and Matched filtering

Table5: Comparison based on technique employed in sensing

Parameter	Suitable method	Techniques depends on
• Prior knowledge of licensed user is unknown • High probability of detection required	Cooperative Spectrum sensing	Huffman Encoding Algorithm
• Signal to noise power ratio played vital role • Deriving Threshold value	Energy Detection Technique	EBSS and PCA Technique
• DAF strategy consideration • If better performance expected than AWGN and i.i.d. Rayleigh channel.	Relay based cooperative spectrum sensing	Over Nakagami-m channels
• Noise variance is key parameter • Basic model is energy detection technique	Energy detection using estimated noise variance	Using estimated noise variance
• Agility of cognitive radio systems.	Energy detection based spectrum sensing	M-cooperative sensing scheme
• Improvement of sensitivity	Asynchronous cooperative spectrum sensing	Using asynchronous cooperative spectrum sensing method

F. Cooperative-Sensing

Main requirements of spectrum sensing is to detect the presence of the primary users as fast as possible. So, the secondary users should continuously monitor the spectrum of the primary users and vacate it as soon as the primary user is detected. Two successive stages are there in spectrum sensing : sensing and reporting. Primary user, CR user and Fusion Centre will be included in cooperative spectrum sensing. Cooperation is proposed in the literature as a solution to problems that arise in spectrum sensing due to noise uncertainty, fading, and shadowing.

Table6: Summary of cooperative sensing methods

S.No.	Method	Technique
1	*Centralized Sensing*	*A* central unit collects sensing information from cognitive devices, identifies the available spectrum, and send this information to other cognitive radios.
2	*Distributed Sensing*	cognitive nodes share information among each and they make their own decisions regarding part of the spectrum they can use. Distributed sensing is more advantageous than centralized sensing because there is no need for a backbone infrastructure and results reduction in cost.
3	*External Sensing*	In external sensing, an external agent performs the sensing and broadcasts the channel occupancy information

IV. CONCLUSION

In this paper summary presented of various spectrum sensing techniques used in cognitive radio to allow access to the secondary user in the case when band of frequency licensed to the main user is free.

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