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
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.

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>
<thead>
<tr>
<th>s.no.</th>
<th>Sensing mechanism</th>
<th>suitable parameter</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In the frequency domain</td>
<td>Frequency</td>
<td>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.</td>
</tr>
<tr>
<td>2</td>
<td>In a specific band w.r.t. time.</td>
<td>Time</td>
<td>The band is not continuously used. There will be times where it will be available for opportunistic usage.</td>
</tr>
</tbody>
</table>
### 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>
<thead>
<tr>
<th>Table 3: Comparison of Algorithms</th>
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<tbody>
<tr>
<td><strong>Drawback</strong></td>
</tr>
<tr>
<td>Single-Radio</td>
</tr>
<tr>
<td>Double-Radio</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>s.no.</th>
<th>Accuracy wise (Low to High)</th>
<th>Complexity wise (Low to High)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Energy detector</td>
<td>Energy detection</td>
</tr>
<tr>
<td>2</td>
<td>Cyclostationary</td>
<td>Waveform-based</td>
</tr>
<tr>
<td>3</td>
<td>Radio identification</td>
<td>Cyclostationary</td>
</tr>
<tr>
<td>4</td>
<td>Waveform-based and Matched filtering</td>
<td>Radio identification and Matched filtering</td>
</tr>
</tbody>
</table>

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.

Table 6: Summary of cooperative sensing methods

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Method</th>
<th>Technique</th>
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<tbody>
<tr>
<td>1</td>
<td>Centralized Sensing</td>
<td>A central unit collects sensing information from cognitive devices, identifies the available spectrum, and sends this information to other cognitive radios.</td>
</tr>
<tr>
<td>2</td>
<td>Distributed Sensing</td>
<td>Cognitive nodes share information among each other and 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 in reduction in cost.</td>
</tr>
<tr>
<td>3</td>
<td>External Sensing</td>
<td>In external sensing, an external agent performs the sensing and broadcasts the channel occupancy information.</td>
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IV. CONCLUSION

In this paper summary presented 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.

REFERENCES


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