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Study of Spectrum Sensing Techniques in Cognitive Radio: A Survey

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Abstract— *the wireless traffic is increasing in an unparalleled way, which causes radio spectrum shortage. The fixed spectrum assignment policy makes this problem more critical. Cognitive radio is one answer to spectrum scarcity problem. In Cognitive radio, the licensed bands are opportunistically accessed when primary user is absent. The first step to a cognitive radio network is the spectrum sensing. An efficient and fast spectrum sensing can make cognitive radio more useful practically. In this paper we discuss several spectrum sensing techniques used in cognitive radio. The vacant frequency spectrum is first sensed by the cognitive radio users, for this purpose several spectrum sensing techniques are used. Spectrum sensing is one of the features of cognitive radio which tells us the availability of vacant bands (also called spectrum holes). In this survey, we analyze the non-cooperative, cooperative and interference based spectrum sensing techniques in cognitive radio. Also in the last, an introduction of some miscellaneous techniques has been given.*

Index Terms— *Cognitive Radio (CR), spectrum sensing, Primary User (PU), fusion center, multi-taper spectrum estimation, Power Spectral Density (PSD).*

I. INTRODUCTION

With the revolution in wireless technology the radio spectrum becomes loaded with the number of users. The federal communications commission (FCC) has published a report in licensed spectrum usage, which shows that most of the allocated channel is not used all the time and some of the bands are heavily loaded [2]. The cognitive radio is one of the solutions of the spectrum underutilization. The concept of cognitive radio was first proposed by Joseph Mitola in his PhD thesis in the year 1999[1]. The cognitive radio observes radio spectrum regularly for availability of spectrum holes and if a vacant band is available, the secondary users then allowed to transmit and receive signals in that band until the primary user is not present. The secondary users should be active enough to continuously checking of vacant bands and can hop from one frequency to the other as soon as primary user came into existence.

The function of Cognitive Radio involves:

- Spectrum sensing.
- Spectrum management.
- Spectrum sharing.
- Spectrum mobility.

In this survey, we analyze the spectrum sensing techniques. The spectrum sensing techniques can be categorized into three main categories viz. non-cooperative detection, cooperative detection, and interference based detection. In section II, the basic idea of spectrum sensing is given with block diagram representing spectrum sensing techniques and their sub-parts. In section III, IV, and V the non-cooperative, cooperative and interference based spectrum sensing techniques are described. In section VI, we cover some of the miscellaneous sensing techniques.

II. SPECTRUM SENSING

Spectrum sensing is a key feature of cognitive radio to use vacant bands more efficiently. Spectrum sensing in cognitive radio can be achieved by different methods, but it is important to choose the best suited method under AWGN and fading environment. The vacant bands in a spectrum are then considered as spectrum holes [1]. In spectrum sensing, the main function of cognitive radio is to detect spectrum holes and transmit and receive data. It is not an easy task, sometimes due to fading or AWGN the cognitive radio can't find spectrum holes and in some cases spectrum holes are shown even if PU is present. The performance of different detectors can be compared by estimating the probability of detection.

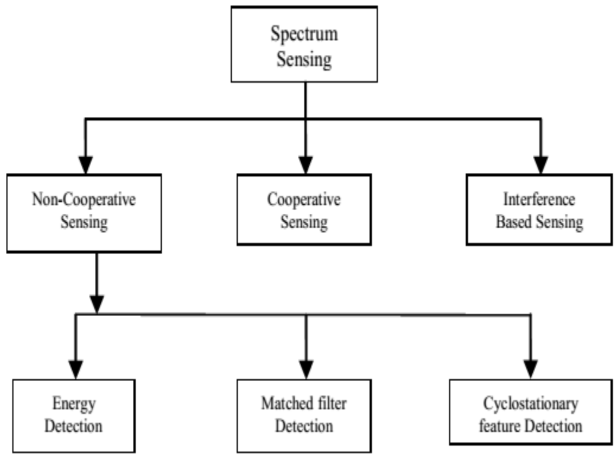

Figure 1. Classification of Spectrum Sensing Techniques [6]

III. NON-COOPERATIVE SPECTRUM SENSING

This technique is also called as transmitter detection, in this technique the CR user has to find the primary transmitter which is transmitting at any given time. The basic model of non-cooperative spectrum sensing is given as:

$x(t) = n(t)$ H0 ; (PU is absent)

$x(t) = s(t) + n(t)$ H1 ; (PU is present)

H0 and H1 represent absence and presence of primary user signal respectively. [4] The transmitter detection techniques are mainly three types:

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A. Energy Detection

Energy detection is considered as the non-coherent detection technique as the CR users doesn't need any prior knowledge of primary users. In this technique the detection is done by comparing received samples with pre-arranged threshold level. This technique is often used due to its simplicity and good performance at low noisy areas. This is the most basic technique as the cognitive radio receiver doesn't need any knowledge on the primary user's signal.

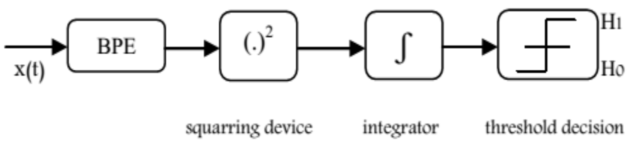

Figure 2. Block Diagram of Energy Detection [4]

H_1 and H_0 represent the presence and absence of primary user signal [4]. This technique can rarely be differentiates between noise and primary user signal presence, also it gives poor performance at low SNR values.

B. Cyclostationary feature Detection

In this technique the transmitted data is considered as a stationary random process, showing periodicity in their statistics like mean, autocorrelation and Cyclostationarity. These features can be extracted through spectral correlation function. By using spectral correlation function, noise energy can be differentiated from the modulated signal energy and the presence of primary user can be detected. The measure of spectral correlation function is shown in figure (3). When α=0 the spectral correlation function yields power spectral density.

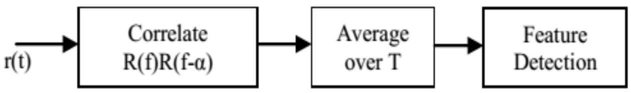

Figure 3. Block diagram of Spectral correlation function [4]

Cyclostationary processes are random process for which the second order statistics such as mean and autocorrelation changes periodically with time. This technique gives better results than energy detection at low SNR region but it is complex and takes more computation time.

C. Matched filter Detection

If the impulse response of any linear filter is the time reversal of the input signal, filter is called as matched filter. The matched filter detectors are optimal linear detectors which use correlation function. If the CR users have prior knowledge of preambles of primary user signals, matched filter detection is an optimal choice. This technique has advantage of least sensing time and high accuracy. The matched filters are generally used to increase signal to noise ratio in the presence of AWGN channel. The time shifted delayed version of original input signal is correlated and a threshold decision is then applied [5].

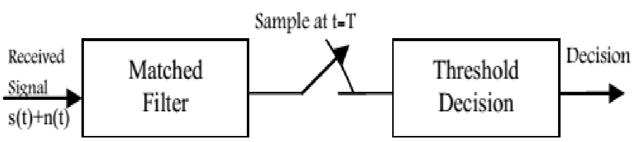

Figure 4. Matched filter Detector [4]

The matched filter output gives maximum SNR value at the observation time (T). The value of T is always greater than t, which means that the filter will wait until the complete signal is received then it will make decision. The output of matched filter receiver is given by:

$$y(T) = h(t) * x(t)|_{t=T}$$

Where h(t) is the impulse response of a linear filter, the matched filter is useful in AWGN channel as it maximizes the SNR value but it makes no change to a fading channel, hence in a fading channel a matched filter detector is not an optimum choice.

IV. COOPERATIVE DETECTION

This technique is useful in Fading, Shadowing or noise uncertainty regions. Due to harsh multipath fading the hidden terminal problem occurs and probability of false alarm increases, cooperative sensing is very helpful in such type of cases. In cooperative sensing number of cognitive radio users cooperate and share their sensing information with each other so that any of the cognitive radio users will detect the presence of primary user signal will inform other users about primary user presence.

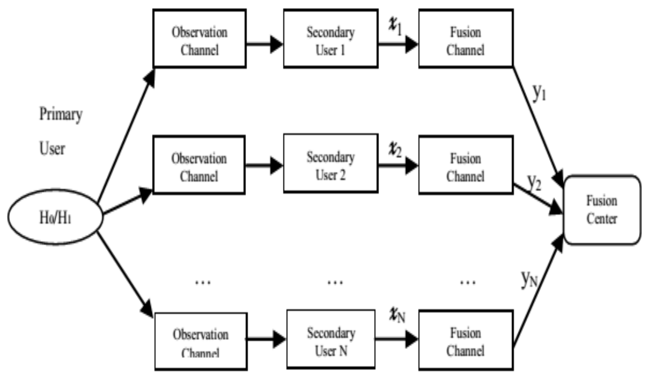

Figure 5. Cooperative Spectrum Sensing in Cognitive Radio [3]

This technique enhances the sensing performance by using the spatial diversity in the observations of spatially located CR users. The sensing time, delay, energy, and operation related to cooperative sensing are some of the major overheads of cooperative sensing technique. This cooperation between CR users is done in three different ways:

A. Centralized Sensing

In centralized sensing, all the sensing information of the cognitive radio users is sent to a centralized unit called as fusion center (FC)

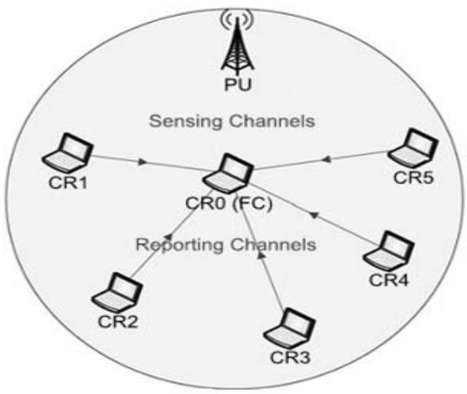

Figure 6. Centralized Sensing [3]

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The fusion centre (FC) is shown in the figure (6) is a central unit. FC will select the frequency band of interest to be sensed and send instructions individually to each cognitive radio user to perform sensing. The information collected by cognitive radio users is send to the FC.

B. Distributed Sensing

In this case, the sensing doesn't depend on the fusion centre for making the decision of primary user presence. The cognitive radio users connect themselves and converge into an integrated decision on the presence of primary user signal. Each CR user sends its sensing data to the other users, received data is then combined with the sensing data by each user and decides whether the primary user is present or not.

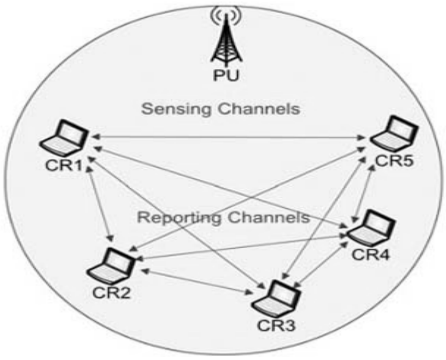

Figure 7. Distributed Sensing [3]

On the basis of distributed sensing, each CR user:

- Will share its sensing data with other CR users.
- The collected data from CR users will be combined with the received data.
- Decides whether PU is present or not.
- Sends its decision to each CR user.

C. Relay Assisted Sensing

This technique is a combination of both centralized and distributed sensing. This technique is implemented where the sensing channel and report channel are not ideal. Although there is a fusion center in relay assisted sensing but it can make a distributed network too and the strong cognitive radio user can serve as relay nodes.

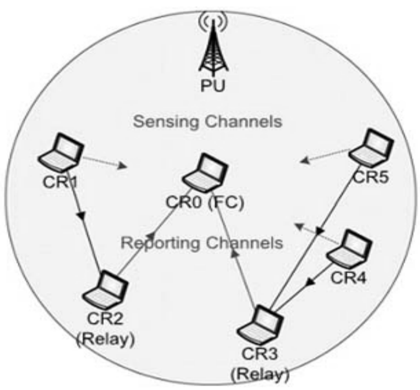

Figure 8. Relay Assisted Sensing [3]

V. INTERFERENCE BASED DETECTION

There are two methods for interference based detection technique to sense unoccupied spectrum in CR. (1) interference temperature management, and (2) primary receiver detection. Interference is typically regulated in a transmitter-centric way, which means interference can be controlled at the transmitter through the radiated power, the out of band emission and location of individual transmitter.

A. Interference Temperature management

In this technique, the CR users coexist through PUs and allowed to transmit at low power. A threshold is set just above the interference temperature limit to restrict secondary users to interfere with primary users. An upper interference limit is set for a given spectrum and the licensed user data is transmitted above this limit and CR users can transmit and receive their data below this limit, such that the CR user are not allowed to cause harmful interference by using the specific band below the interference limit.[11]

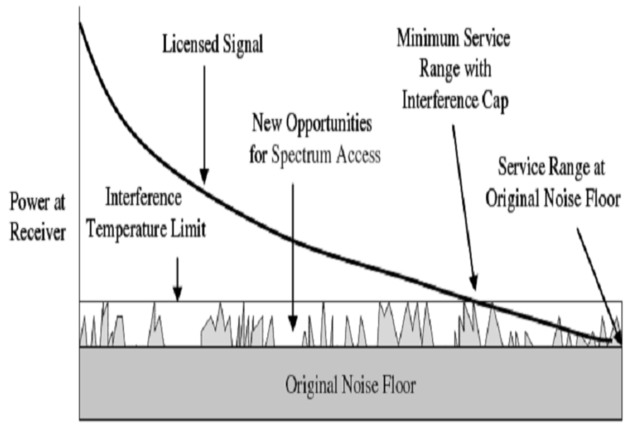

Figure 9. Interference Temperature model [6]

B. Primary Receiver Detection

In this technique, the leakage power of local oscillator in super heterodyne receiver is emitted by RF front end of primary receivers [11]. This technique has a bottleneck that detecting the leakage power of a primary user receiver for a cognitive radio user is impractical. If CR users use this varying parameter for detecting primary user detection it would cause too much error.

VI. MISCELLANEOUS TECHNIQUES

A. Multi-Taper Spectrum Estimation

The technique was proposed by Thomson in 1982 before the CR concept were introduced. The idea of this technique is that the Fourier transform of slepian vectors have the maximal energy concentration in bandwidth fc-W to fc+W under finite sample size constraints. By using this characteristic, CR user can easily identify the spectrum opportunities in the given band.

B. Filter Banks based Spectrum Estimation

This technique is a simplified version of multi-taper spectrum estimation technique which uses only one prototype filter for each band. This technique is proposed for multi-carrier modulation based CR systems by using a pair of matched Nyquist filter [9]. Multi-taper spectrum estimation is better for small samples whereas this technique is better for large samples.

C. Wavelet Based Detection

This technique is widely used in image processing for edge detection applications. The technique was proposed by Tian

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and Giannakos in the year 2006. The wavelets are used for detecting edges in power spectral density (PSD) of a wideband channel. These edges of PSD are the boundaries between spectrum holes and occupied bands and through this it helps to find spectrum holes in licensed spectrum [5].

D. Radio Identification Based Detection

This technique is used in the perspective of European Transparent Ubiquitous Terminal (TRUST) project in the year 2000. The technique uses a number of extracted features such as transmission frequency, range, modulation technique etc. Once the features are extracted from the received signal, CR users then utilize these features and can select appropriate transmission parameters for them.

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