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Overview of cognitive radio and Spectrum Sensing Techniques.

Shabnam, Rita mahajan

Abstract— The need for a flexible and robust wireless communication is becoming more important in recent times. The future of wireless networks is thought of as a union of mobile communication systems and internet technologies to offer a wide variety of services to the users which has put a lot of constraints on the available radio spectrum which is limited and precious. In fixed spectrum assignments there are many frequencies that are not being properly used. So cognitive radio helps us to use these unused frequency bands which are also called as "White Spaces". This is a unique approach to improve utilization of radio electromagnetic spectrum. In establishing the cognitive radio there are 4 important methods. In this paper we are going to discuss about the Cognitive radio characteristics and benefits. The most important method to implement cognitive radio i.e., "spectrum sensing" is discussed in detail. Various spectrum sensing techniques that are involved in spectrum sensing along with their merits and demerits.

Index Terms— **Primary User, Secondary User, Spectrum Sensing, Signal Processing Techniques, Energy Detector.**

I. INTRODUCTION

The need for a flexible and robust wireless communication is becoming more important in recent times. The growing demands in wireless applications have put a constraint on the available radio spectrum which is a natural scarce resource. But the truth is, bandwidth is not scarce but is underutilized. Today's spectrum management is based on fixed frequency assignment resulting in highly ineffective utilization of spectrum. So the requirement is of dynamic spectrum management model (cognitive radio) as a technology tool to realize the goal to provide a new solution in addressing the issue of spectrum scarcity.

Cognitive Radio works on this dynamic Spectrum Management principle which solves the issue of spectrum underutilization in wireless communication in a better way. It has an intelligent layer that performs the learning of environment parameters in order to achieve optimal performance under dynamic and unknown situations. The key feature of a Cognitive Radio is its ability to recognize the unused parts of spectrum that is licensed to a primary user and adapt its communication strategy to use these parts while minimizing the interference that it generates to the primary user. Based on the interaction with environment in which it operates cognitive radio will change its transmission parameters like waveform, protocol, operating frequency etc. Figure 1 shows the Dynamic Spectrum Access in Cognitive Radio.

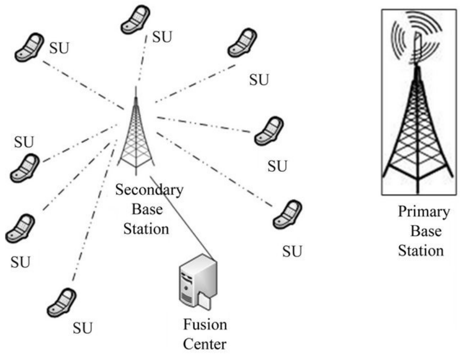

Figure1:Dynamic spectrum access

Four major functions of cognitive radio are: Spectrum Sensing, Spectrum management, Spectrum Sharing and Spectrum Mobility. Spectrum Sensing is to identify the presence of licensed users and unused frequency bands i.e., white spaces in those licensed bands. Spectrum Management is to identify how long the secondary users can use those white spaces. Spectrum Sharing is to share the white spaces (spectrum hole) fairly among the secondary users. Spectrum Mobility is to maintain unbroken communication during the transition to better spectrum. The basic Cognitive cycle performs the following tasks.

- Spectrum Sensing.
- Spectrum Management.
- Spectrum Sharing.
- Spectrum Mobility.

Characteristics of cognitive radio:
Following are CRs two main characteristics:
1) Cognitive capability: It refers to the ability of the cognitive radio to sense the environment or channels used for transmission and derive the information about the state of the channel.
2) Reconfigurability: It refers to programming the radio dynamically without making any changes to its hardware section. Cognitive radio is a software based radio and not hardware based so it has the capability to switch between different wireless protocols and also supports a number of applications.

In terms of occupancy, sub bands of the radio spectrum may be categorized as follows:
A) White spaces: These are free of RF interferers, except for noise due to natural and/or artificial sources.
B) Gray spaces: These are partially occupied by interferers as well as noise.

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C) Black spaces: The contents of which are completely full due to the combined presence of communication and (possibly) interfering signals plus noise.

Figure 2 shows the White Spaces and Used Frequencies in Licensed Spectrum.

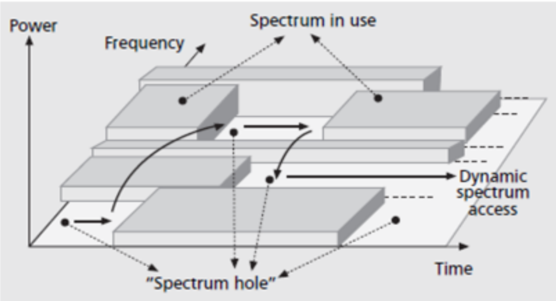

Figure2: Illustration of white spaces in licensed band

Benefits of CR: The future requirement of spectrum will be met and this is the basic reason for implementing CR. From the user's perspective the suitability, availability and reliability will be enhanced leading to improved quality of service. Demand for higher bandwidth services will be catered. CR makes it easier to trade between spectrum and users (Spectrum liberalization).

Hence efficient spectrum utilization, improved interconnectivity, increased scalability etc are the advantages of implementing CR

II. SPECTRUM SENSING

Spectrum sensing refers to the capability of timely sensing the spectrum holes. It is important requirement because a CR is designed to be aware of and sensitive to the changes in the environment. It enables the CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary user. Secondary user (SU) should be equipped with highly reliable spectrum sensing function and should be able to detect spectrum in a continuous and real time way. When compared to all other techniques, Spectrum Sensing is the most crucial task for the establishment of cognitive radio based communication mechanism as cognitive radio can allocate only an unused portion of spectrum hence it has to monitor the available spectrum bands, capture their information and then detect spectrum holes.

Existing spectrum sensing technologies can be categorized as:

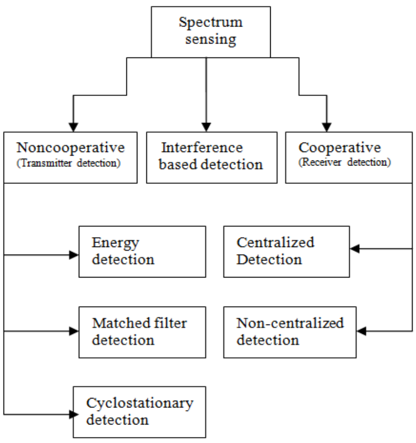

Figure3: Classification of spectrum sensing techniques

III. CLASSIFICATION OF SPECTRUM SENSING TECHNIQUES

1) Non cooperative sensing: In this technique each cognitive radio senses itself and uses its sensing data to give a decision on channel state that is idle or busy whereas in cooperative sensing CR shares its sensing data with others and utilize the sensing outcomes of others to give a decision. The cognitive radio will configure itself according to the signals it can detect and the information with which it is pre-loaded. Non cooperative spectrum sensing includes:

a) Primary transmitter detection: The detection of the signal from the primary transmitter is Based on the received signal at CR users the detection of primary users is performed. This approach includes matched filter (MF) based detection, energy based detection, cyclostationary based detection etc.

2) Cooperative and collaborative detection: The primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the spectrum load smoothing algorithm or external detection.

3) Interference temperature detection: In this approach, CR system works as in the ultra wide band (UWB) technology where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users.

A. Primary Transmitter Detection: few primary transmitter detection techniques are discussed below. They are

1) Energy Detection: Energy detection is the signal detection mechanism using an energy detector to specify the presence or absence of signal in the band. It has moderate computational complexities and can be implemented in both time and frequency domains. It is a simple detector which detects the total energy of the received signal over specified time duration. A threshold value is required for comparison of the energy found by the detector. Energy greater than the threshold values indicates the presence of the primary user.

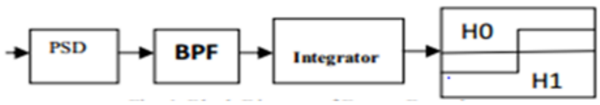

Figure4: Block diagram of energy detector

Where H0 = Absence of User.

H1 = Presence of User.

The block diagram for the energy detection technique is shown in the Figure 4. 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

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of the primary user. The threshold value can set to be fixed or variable based on the channel conditions .

y(k)=n(k)………………
H0 y(k)=h * s(k) + n(k)……H1

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∊ {1, 2….N} at the signal detector, then a decision rule can be stated as,

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 ED 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) ED cannot be used to detect spread spectrum signals.
The only advantage is moderate computational complexity as no prior information is required.

2) Matched filter:

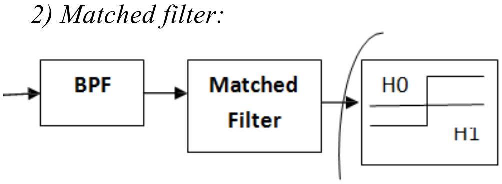

Figure5: Block diagram of matched filter

The block diagram is shown in figure 5.

Where H0 = Absence of User.

H1 = Presence of User.

The Matched Filter Technique is very important in communication as it is an optimum filtering technique which maximizes the signal to noise ratio (SNR). It is a linear filter and prior knowledge of the primary user signal is very essential for its operation. The operation performed is equivalent to a correlation. The received signal is convolved with the filter response which is the mirrored and time shifted version of a reference signal. Its main problem is it requires pre-knowledge of Primary user which is hard to get. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as:

$$Y[n] = \Sigma\, h[n-k]\, x[k]$$

Where 'x' is the unknown signal (vector) and is convolved with the 'h', the impulse response of matched filter that is matched to the reference signal for maximizing the SNR. Detection by using matched filter is useful only in cases where the information of the primary user is known to the SR.

Advantages:-
This technique requires shorter sensing time for certain probability of false alarm or probability of detection.

Matched filter detection performs well in stationary Gaussian noise when the CR user has the information of the primary user signal.

Disadvantages:-
Matched filter detection requires the exact synchronization and prior knowledge of primary user signal.

Implementation complexity of sensing unit is impractically large since cognitive radio user need receivers for all signal types.
Since various receiver algorithms need to be executed for detection, it results in large power consumption.

3) Cyclostationary based detection: Cyclostationary based sensing use the periodicity property of signals. The signals which are used in several applications are generally coupled with sinusoid carriers, cyclic prefix, spreading codes, pulse trains etc. which result in periodicity of their statistics like mean and auto-correlation. Such periodicities can be easily highlighted when cyclic spectral density for such signals is found out. Primary user signals which have these periodicities can be easily detected by taking their correlation. Fourier transform of the correlated signal results in peaks at frequencies which are specific to a signal and searching for these peaks helps in determining the presence of the primary user. Noise is random in nature and as such there are no such periodicities in it and thus it doesn't get highlighted on taking the correlation.

Pros:- Works well for low SNR conditions. It has the capability to distinguish between primary user and noise. It can differentiate between different types of signals
Cons**:-**Since all the cycle frequencies are calculated so the computational complexity is higher.

B) *Cooperative techniques*

There are broadly 2 approaches to cooperative spectrum sensing:
1) Centralized approach: Here in this technique we have Cognitive Radio controller called fusion centre (FC) within the network that collects the sensing information. FC then analyzes the information and determines the bands that can and cannot be used, when one Cognitive Radio detects the presence of primary user then it intimates the Cognitive Radio controller about it. Then that controller informs all the Cognitive radio users by broadcast method.

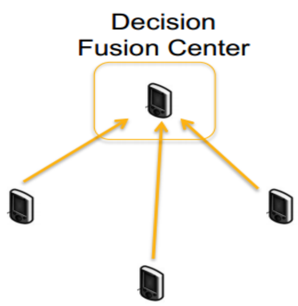

Figure6: Centralized approach

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2*) Decentralized approach:* unlike centralized approach, distributive cooperative sensing does not depend on a FC for making cooperative decisions. Cognitive Radio will independently detects the channel and will vacate the channel when it finds a primary user without informing the other users. Thus Cognitive Radio users will experience bad channel realizations and detect the channel incorrectly thereby causing interference at the primary receiver which is not advantageous when compared to coordinated techniques.

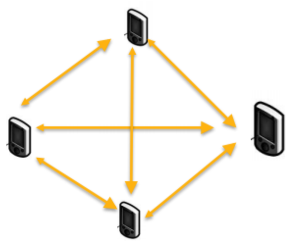

Figure7: Decentralized approach

IV. COMPARATIVE ANALYSIS OF VARIOUS SPECTRUM SENSING TECHNIQUES

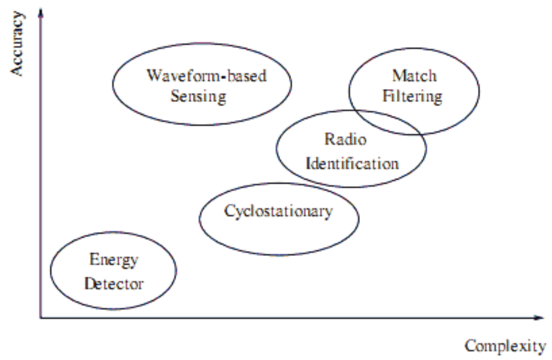

Figure8: Comparative analyses of different techniques.

Among the above 3 methods, Energy detection is a basic and popular method. Since Cyclostationary or Feature detection based spectrum sensing uses the exclusive prototype of the signal to sense its existence. But it is more complicated to implement and sensitive to the impairments between the cyclic frequency, carrier frequency and sampling frequency.
Matched filter Performs coherent detection. But it acquires optimal solution to the signal detection but it requires priori knowledge on the received signal.

V. CONCLUSION

As the usage of frequency spectrum is increasing day by day, it is becoming more valuable and we need to access the frequency spectrum wisely. For this purpose we are using Cognitive Radio as static spectrum allocation is no more a solution. This paper presents the overview of cognitive radio and discusses the characteristics and benefits of cognitive radio. Spectrum sensing and its techniques are discussed in detail. Comparative analysis of various spectrum sensing techniques is done and the results showed that energy detection based spectrum sensing is widely used because it does not require the transmitted signal properties and thus has moderate computational complexities as compared with other techniques.

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First Author : Shabnam, B.TECH. in ECE from Giani zail singh college of Engineering and technology ,Bathinda-Punjab, in the year 2013 and currently pursuing M.E. in Electronics from PEC University of Technology, Chandigarh.
Email id: shabnam2209@gmail.com
Second Author Rita mahajan work, Associate Professor in Department of ECE, PEC University of Technology, Chandigarh.
Email id: Ritamahajan@pec.ac.in

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