A Review on Spectrum Sensing Techniques in Cognitive Radio Network

Sk. Muntaj, D. Akhila John

Abstract- **The importance of spectrum is rapidly increasing in wireless technologies and hence there by increasing the traffic of the spectrum. More than 70% of the available spectrum is not utilized efficiently.i.e the spectrum utilization varies from 5% to 85%. Due to the shortage of frequencies bandwidth is becoming more expensive. For efficient utilization of the spectrum, it is required to determine the spectrum whether it is being used by the primary user or not. It leads to the invention of cognitive radio. Cognitive radio is referred as the adoption of radio parameters using the sensed information of the spectrum. Spectrum sensing is the main function of cognitive radio, which enables the user to search for free bands. Which is termed as the spectrum hole and is defined as the frequency band which is free be used. The spectrum hole can be utilized by the secondary user with high spectral resolution capability. Various spectrum sensing techniques available to sense the unused spectrum are discussed here.**

***Index Terms*- Cognitive Radio (CR), Spectrum Sensing, Primary User (PU) and Secondary User (SU).**

I. INTRODUCTION

The term cognitive radio is first coined in an article by Joseph Mitola III and Gerald Q. Maguire, Jr in1999. In the last decades, there has been an enormous increase of wireless communication Systems [1]. The usage of frequency bands or spectrum is strictly regulated, and allocated to specific communication techniques. Spectrum is a scarce resource, and licensed spectrum is intended to be used only by the spectrum owners i.e. licensed users called as primary users (PU). Cognitive radio is a new technology which allows us to reuse the licensed spectrum in an unlicensed manner. The unused resources are often referred to as spectrum holes or white spaces. The spectrum hole can be reused by cognitive radio, sometimes called secondary users (SU). Service providers are facing a problem in a situation in which it is required to provide larger amount of spectrum to satisfy the increasing quality of service (QOS) requirements to the users. This problem is addressed by using cognitive radio network. Cognitive radio (CR) a transceiver is placed which can intelligently detect the used and unused frequency bands and instantly move the vacant channels while avoiding the occupied ones, which enables the use of available radio-frequency (RF) spectrum while minimizing interference the interference to other users. That's why it is known as an intelligent device that can coexist with licensed users without affecting their quality of service. There are mainly two types of users in the cognitive radio network, one is Primary User (PU) and the other one is Secondary User (SU). Primary Users (PU) are the licensed users and they have the right of priority in using certain stable frequency band for communications. Secondary Users (SU) are allowed to use the frequency spectrum only in the absence of primary users and they do not interfere with the PU. So the ability of sensing an idle spectrum and the ability to temporarily utilize a spectrum without interfering with Primary Users are two essential components required for the success of cognitive radios.

The common definition for Cognitive Radio is given as *"Cognitive Radio is a radio for wireless communications in which either a network or a wireless node changes its transmission or reception parameters based on the interaction with the environment to communicate effectively without interfering with the licensed users*."

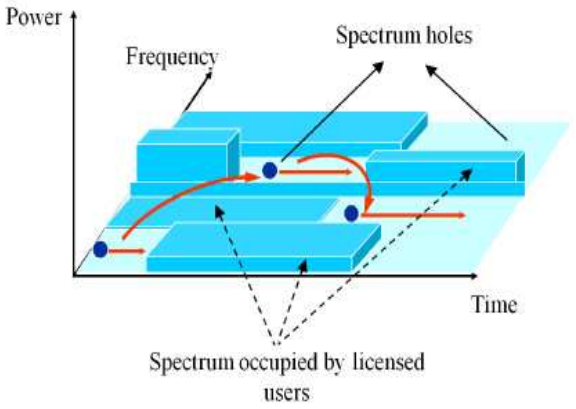

Fig 1: Representation of Spectrum Holes

To implement without Interference to the primary signal, the cognitive radio needs to sense the availability of the spectrum before accessing the channel. So while designing a Cognitive Radio network the main challenges we have to consider are: spectrum sensing, interference avoidance, quality of service.

II. COGNITIVE RADIO

In wireless communication system Cognitive Radio is a technology which is aware of the environment and its

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changes and can adapt its transmission parameters accordingly, Fig 2 shows the basic cognitive radio cycle.

A. Characteristics of Cognitive Radio

Cognitive Capability: The Characteristic which has the ability to sense the unused spectrum at a specific time and location (Spectrum Hole) is known as the Capability of Cognitive Radio.

Reconfigurability: Reconfigurability is the ability to receive and transmit signals at different frequency bands, which enables the cognitive radio to reconfigure its parameters and select the best available band [6].

B. Functionalities of Cognitive Radio

Spectrum sensing: At any given time and location the user has the ability to sense the unused spectrum (spectrum hole).It is the first important functionality of Cognitive Radio system [3].

Spectrum management: After determining the spectrum holes, based on the available spectrum band and other policies, Cognitive Radio assigns the spectrum to the user.

Spectrum mobility: Cognitive Radio user or secondary user is allowed to vacate the spectrum in the presence of any licensed user or primary user and it has to move to next available spectrum band [2].

Spectrum sharing: Among the available multiple Cognitive Radio users the cognitive radio network has to provide a fair and optimal spectrum allocation method.

As shown in Fig 2 Spectrum sensing detects the unused spectrum band, the analysis of spectrum holes is performed in spectrum analysis and their characteristics are estimated, by using spectrum decision the available spectrum band is assigned to cognitive users. Depending upon the radio environment changes the decision of Cognitive Radio also changes.

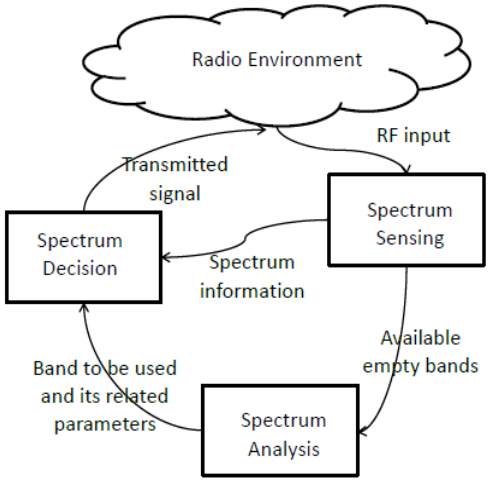

Fig 2: Basic Cognitive Radio Cycle

C. Network access types in Cognitive Radio

Basically there are three Network access types which are as shown in the below Fig 3.

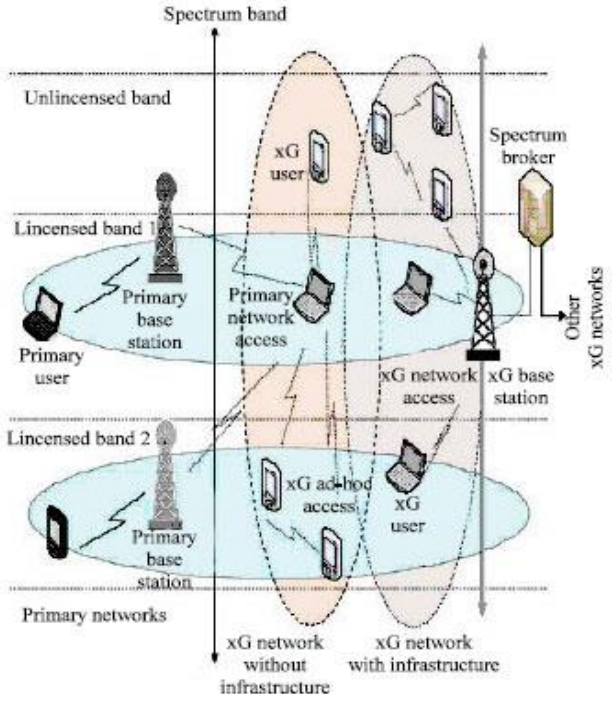

Fig 3: Architecture of Cognitive Radio

CR Network Access: On both the licensed and unlicensed spectrum bands it can access their own base station.

CR AD-HOC Access: By using the ad hoc connection on both the licensed and unlicensed spectrum bands cognitive radio can communicate with other Cognitive Radios.

Primary Network Access: Through the licensed bands cognitive radios can access their primary base station.

As shown in Fig 3 [9], the network which has the right to use the licensed band is known as primary network and the user of that network is known as Primary User, primary base station is used to provide signals to primary network. The network which is able to access the spectrum in the absence of primary user is known as cognitive network and the user is known as Secondary User or cognitive radio user, cognitive base station is used to provide signals to cognitive radio network. Spectrum broker is a central network entity which is able to share the spectrum resources among different cognitive radio networks.

The network architecture may be centralized and distributed. In centralized network base station is responsible for gathering the information from all other CR users to detect the primary user. In distributed network CR exchange messages among each other to get the desired objective.

D. Applications of Cognitive Radio Networks

Cognitive Radio networks can be applied to the following cases:

Leased network: The primary network may provide a leased network by allowing cognitive radio user to access their licensed spectrum without disturbing the communication of the primary user.

Cognitive mesh network: Cognitive Radio technology enables the access to larger amount of spectrum (for broadband connectivity) therefore cognitive radio networks will be a good choice to meet the requirements of mesh networks.

Emergency network: In the case of natural disasters, when primary networks temporarily disable their spectrum band, it can be used by the cognitive radio users. The cognitive radio networks can communicate on the available spectrum band in an ad hoc mode without using any infrastructure and by maintaining the communication priority and response time.

Military network: Cognitive radio networks can enable the military radios to choose arbitrary intermediate frequency (IF) bandwidth, modulation schemes, and coding schemes, adapting to the variable radio environment of battlefield.

III. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the main challenge to the Cognitive Radio system. A spectrum hole has to be determined by using spectrum sensing technique in the radio environment. There are so many different methods are available to identify the presence of signal transmission, which all are in the early development stage only. Finding out the spectrum status and activity by periodically sensing the target frequency band is the main goal of spectrum sensing. Cognitive radio transceiver detects the spectrum which is unused or spectrum hole and also determines the best available method to access the spectrum without interfering the transmission of licensed user. Different types of spectrum sensing techniques are shown in Fig 4.

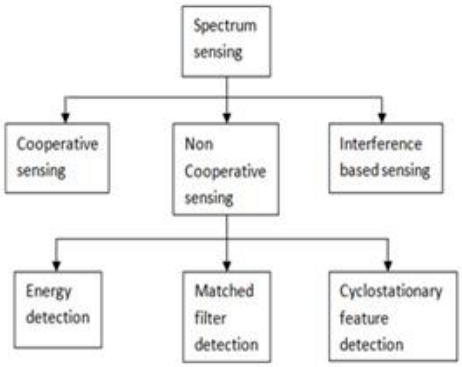

Fig 4: Classification of Spectrum sensing techniques

Detection may be cooperative and non-cooperative. In cooperative spectrum sensing the effect of the communication of one node on the other nodes is considered i.e. information from many cognitive radio users are combined to detect the primary user. It helps to overcome the multipath fading and shadowing effects which will increase its usability. In Non-cooperative technique only a single node is considered for effective communication i.e. the cognitive radio user can detect the signal of primary user by its own observation and analysis is independent of the other CR users. Non cooperative techniques are also known as transmitter detection techniques and these are termed as narrowband spectrum sensing techniques. Based on the received signal at Cognitive radio users the detection of primary users is performed. This approach includes energy detection, matched filter (MF) detection, cyclostationary feature detection, etc.

A.ENERGY DETECTION: The availability of primary user is determined by using the spectrum sensing technique, which is the main aim to decide whether there is primary user or not. By using the transmitter detection technique each cognitive radio (CR) must have the ability to determine the presence or absence of the Primary user (PU) independently in a specified spectrum. The hypothesis model for transmitter detection that is, the signal detected by the Secondary user (SU) is given as:

$$H0: y(t) = w(t)$$
$$H1: y(t) = h*x(t) + w(t) \quad (1)$$

Where H0 indicates that the primary user is absent i.e.no signal is transmitted, and H1 indicates that the primary user is present i.e. signal is transmitted. Y (t) is the signal received by the secondary user, x (t) is the signal which is transmitted, w (t) is the Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 and 'h' is the amplitude of the channel [8].

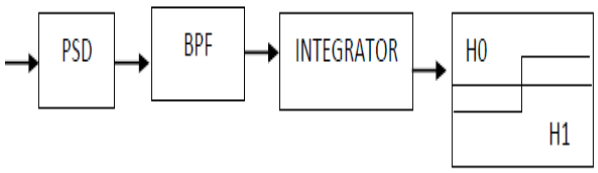

Fig 5: Block diagram of Energy detection technique

It is the common way of spectrum sensing technique for its low computational and implementation complexities. Which is a non-coherent detection method and it is used to detect the licensed user signal. Here no prior knowledge of primary users signal is required and is based on the use of the FFT (Fast Fourier transform). FFT transforms a signal from time domain to frequency domain representation and determines the power in each frequency of the signal resulting the Power Spectral Density (PSD) function.

Figure 5 [7] shows the block diagram of energy detection technique in which the signal is applied to the band pass (BP) filter to select the channel and it is integrated over the time interval. At Last output of the integrator is compared with a threshold to determine whether the primary user is present or not. Depending on the channel conditions the threshold value can be fixed or variable.

Advantages:

I. No prior knowledge of primary signal is required.
II. Computational and implementation complexity is low.
III. Low power consumption.

Disadvantages:

I. It cannot distinguish between noise and primary user especially at low SNR values.
II. Issues related to selecting a proper threshold for comparison purposes.

B.MATCHED FILTER: Matched filter detection technique is a coherent detection technique in which the primary signal is detected by comparing the received signal or from the extracted signal characteristics with prior knowledge of primary signal [4]. This is an optimal detection technique in which the received signal-to noise ratio (SNR) is maximized and it takes less time to sense the spectrum when compared with cyclostationary feature detection technique and takes more time than energy detection technique.

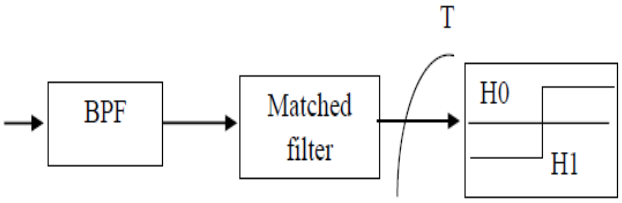

Fig 6: Block diagram of Matched filter detection technique

Where H0=Absence of primary user
H1=Presence of primary user
T=Threshold value

Matched filter determines the presence of the PU by performing correlation in between the signal and time shifted version and comparing the result in between the predetermined threshold and output of matched filter. The matched filter detection operation is expressed as:

$$Y[n] = \Sigma\, h\,[n-k]\; x\,[k] \qquad (2)$$

Where 'x' is the signal or vector which is unknown and is convolved with the 'h', which is the impulse response of the matched filter which is matched to the reference signal for maximizing the SNR. Matched filter technique is used only when the knowledge of primary signal is known to CR user.

Advantages:

I. Optimal detector as it maximizes the SNR (signal to noise ratio).
II. The sensing time is low when compared with other techniques.

Disadvantages:

I. It requires prior knowledge of the primary user signal.
II. Computational complexity is high when compared with energy detection technique.
III. As it requires a dedicated receiver for every type of primary user power consumption is large.

C.CYCLOSTATIONARY FEATURE DETECTION: In Cyclostationary signals, the mean value and autocorrelation function have periodicity. Cyclostationary feature detection is based on the introduction of periodic redundancy into a signal by sampling and modulation. Periodicity of the received primary signal to identify the Primary User (PU) is exploited by Cyclostationary feature detector which measures property of a signal namely Spectral Correlation Function (SCF) [5].

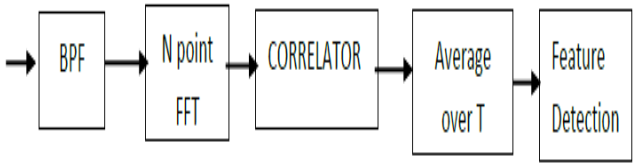

Fig 7: Block diagram of Cyclostationary feature detection technique

Spectral Correlation Function (SCF) is defined as the Fourier transform of autocorrelation function which is given as,

$$s_x^{\alpha}(f)=\int_{-\infty}^{\infty} R_x^{\alpha}(\tau)e^{-j2\pi ft}d\tau \qquad (3)$$

Where $R_x^{\alpha}(\tau)$ is cyclic autocorrelation function which is given as,

$$R_x^{\alpha}(\tau) = \frac{1}{To}\int_{t=-To/2}^{To/2} R_x(t,\tau)\, e^{-j2\pi\alpha t}dt \qquad (4)$$

The modulated signal from the additive noise can be differentiated by using cyclostationary feature detector implementation, i.e.it distinguish Primary User signal from noise signal. By using the information embedded in the Primary User signal it is used at very low SNR detection level which does not exist in the noise. The number of signals, their modulation types, presence of interferers and symbol rates are the detected features. If the correlation factor is greater than the threshold then it means that there is a primary user in radio environment.

Advantages:

I. It works well under low SNR conditions.

II. It has the capability to distinguish between primary user and noise.
III. It can differentiate between different types of signals.

Disadvantages:
I. Computational complexity is high.
II. It takes more time to sense the spectrum.

Along with these techniques we also have some other techniques such as

D.WAVELET BASED SENSING: Edges in the frequency spectrum results due to transition in frequency of the signal. Presence of an edge indicates the presence of Primary User in band. In this technique frequency band is divided into a number of sub-bands each characterized by its own changes in frequency. The wavelet transform is done on these sub-bands which give the information about the exact location of the different frequency location and spectral densities which are different from the conventional Fourier transform. Fourier transform is only able to show the different frequency components but not the locations. The working of wavelet based sensing is as shown in fig 8.

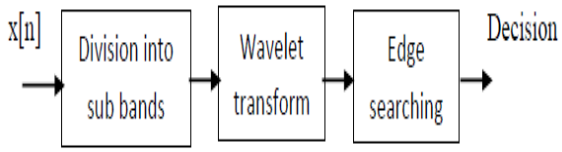

Fig 8: Working of Wavelet based sensing

Advantages:

I. It can be easily adapted to dynamic PSD structures.

Disadvantages:

I. In order to characterize the entire bandwidth higher sampling rates are required.

E. WAVEFORM BASED SENSING: In waveform based sensing for the detection and synchronization purpose of the signal Preambles, Mid-ambles, pilot carrier and spreading sequences, are added intentionally as knowledge of patterns. Preambles are sent just before the start of the data sequence whereas mid-ambles are transmitted in the middle of the data. The more the length of these known patterns, more will be the accuracy of the detection. The working of waveform based sensing is shown in Fig 9.

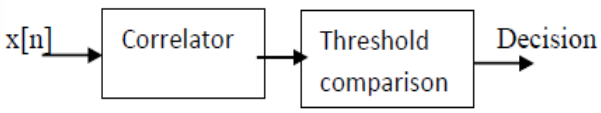

Fig 9: Working of Waveform based sensing

Where x (n) is the received signal, which is correlated with a known pattern and the output of the correlator is compared with a threshold and finally the decision is taken about the presence of primary user depending upon the threshold value.

Advantages:

I. The sensing time is less than the energy detector.
II. It is more reliable than energy detector.

Disadvantages:

I. Lower efficiency of the spectrum results when higher accuracy is required by using the long length of known pattern.

F.MULTIPLE ANTENNA BASED SENSING: For transmission of signals multiple transmitters and multiple receivers are used i.e. MIMO system in which the sensing scheme is based on the eigen values.

The two basic steps for MIMO system are:

1. Test statistics is designed by using the co-variance matrix eigen values. In this method two algorithms are generally used, one being the maximum eigen value detection and the other being condition number detection.
2. Deriving probability density function (PDF) of the test statistics or eigen values so that sensing performance can be quantified.

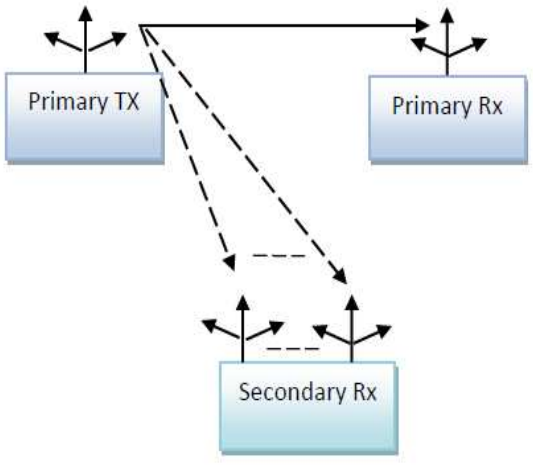

Fig 10: MIMO system detection.

Advantages:

I. The noise power uncertainty is removed.
II. No prior knowledge of the received signal.

Disadvantages:

I. Due to multiple antennas cost of the detector is high.
II. Complexity is high. .

IV. MODULATION TECHNIQUES

In communication systems the two main considerations are (i) Transmission power (ii) Channel bandwidth.

Various modulation schemes are used for the transmission of signals. The signaling rate will be reduced if two or more bits are combined in symbols. Thus, the frequency of the carrier is also reduced. This in turn reduces the transmission channel bandwidth. By grouping the bits into symbols, the transmission channel bandwidth is reduced. To convert the bits into symbols various modulation schemes are used such as BPSK, QPSK, and M-ary PSK etc.

The best trade-off between power and bandwidth requirements is offered by the QPSK (M=4) among the family of M-ary PSK signals. For M>8, power requirements become excessive so they are not widely used in practice. As M is increased, the bandwidth efficiency is improved and also the probability of symbol error improves.

V. CONCLUSION

As the usage of frequency spectrum is increasing day by day, it is becoming more valuable. So it is required to access the frequency spectrum very wisely. For this purpose we are using the Cognitive Radio network to access the spectrum in less time and to use the spectrum efficiently. In this paper the discussion is about the various spectrum sensing techniques which are used for the detection of primary user and thereby allocating the spectrum hole to the secondary user (SU) in the absence of primary user (PU).

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