Global Journal of Researches in Engineering
Electrical and Electronics Engineering
Volume 13 Issue 15 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Cognitive Radio Approach : Spectrum Sensing

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Abstract- In present days the wireless communication has developed quickly. This demand on wireless application has put several limitations on the existing radio spectrum which is precious and limited. Various frequency bands are not used properly in the fixed spectrum assignment but, the cognitive radio more helpful to utilize these frequency bands which are called as white spaces. This is an exclusive approach to improve use of radio electromagnetic spectrum. There are four methods to establish the cognitive radio. This report explain the first method i.e. spectrum sensing and describe the issues, techniques and challenges of this method.

GJRE-F Classification : FOR Code: 890405

Strictly as per the compliance and regulations of :

Cognitive Radio Approach : Spectrum Sensing

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I. Introduction

The available Electromagnetic Spectrum band is becoming piled up day by day, as there is increasing demand for the requirement of wireless communication applications. Several researchers stated that the licensed spectrum is not use correctly because of static allocation spectrum. However, it is more complex to discover available bands either to develop vacant band or to set up a new service. To overcome these problems the researchers implement Dynamic Spectrum Management this improves the available spectrum utilization.

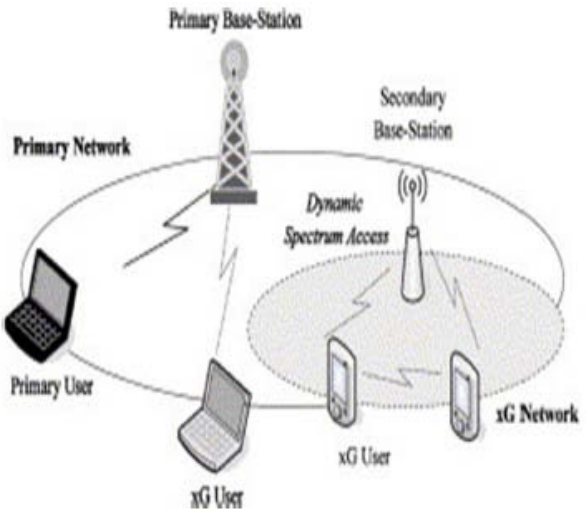

Figure 1 : Dynamic Spectrum Access

The cognitive radio works by depending on the principle of dynamic Spectrum Management which avoids the problems of utilization of spectrum in wireless communication. This radio service supplies highly reliable communication and in this communication the secondary users (unlicensed users) utilizes the unused spectrum of the primary users (licensed users). Depending on the interaction with environment this cognitive radio technology provides different transmission parameters such as networking, operating frequency, protocol and wave form etc. the below figure shows the Dynamic Spectrum Access in Cognitive Radio, Cognitive radio technology has four key functions they are:

a) Spectrum Sensing: this function recognizes the unused frequency bands and presence of licensed users i.e. Spectrum hole (white space) in those licensed bands.
b) Spectrum management: this function recognizes the time period of the unlicensed users (secondary users) can use those white spaces.
c) Spectrum Mobility: this function maintains the unbroken communication during the transition to better spectrum.
d) Spectrum Sharing: this function used to share the spectrum hole (whiter space) in between the unlicensed users (secondary users).

The radio spectrum technology should be categorized into 3 types based on the sub bands and occupancy they are:

White spaces: This type of space is free for the RF interferers but not for noise because of artificial and natural sources.

Gray spaces: This color space is partially covered with noise as well as interferers.

Black spaces: this total color space is full up due to the joint presence of interfering signals plus noise and communication.

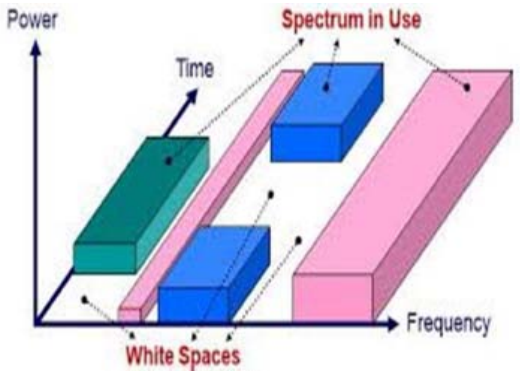

Figure 2 : White Spaces and Used Frequencies in Licensed Spectrum

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Compared to various techniques and method, Spectrum sensing is the difficult task for formation of cognitive radio based communication.

II. Spectrum Sensing

The primary aim of this cognitive radio technology is to the secondary users need to identify the presence of primary users and to depart the frequency band quickly and emerge the equivalent primary radio to avoid interference to primary users.

Spectrum sensing technique is classified into two types. They are:

Direct Techniques: this is also called as frequency domain approach. This technique estimation is complete directly from the signal approach.

Indirect Technique: this technique also called as time domain approach and this technique estimation is carried out by using autocorrelation of the signal.

Several classifications depending on the needs of spectrum sensing as discussed below:

a) Spectrum Sensing for Spectrum opportunities

Primary transmitter detection: the detection and presence of primary users performance is depending on the received signal of CR users. This detection could be done with various approaches such as energy based detection, waveform based detection, Primary Transmitter Detection, matched filter (MF) based detection, covariance based detection and cyclostationary based detection etc.

Cooperative and collaborative detection: the key signals of spectrum sensing are detected by cooperating or interacting with other users. This method can be executed as either speared the indirect approach by the external detection or spectrum load smoothing algorithm or by accessing the spectrum coordinated by spectrum server.

b) Spectrum Sensing for Interference Detection

i. Interference temperature detection: in this method the CR system uses the ultra wide band (UWB) technology. In this approach the secondary users synchronized with primary users and utilizes low transmit power and this signal or power controlled by the interference temperature level. Hence, this approach solves the problems of primary users.

ii. Primary receiver detection: in this approach the spectrum and interference opportunities are recognized by primary receiver's local oscillator leakage power.

c) The Proposed Spectrum Decision Framework

The main function of CR scenario is to spectrum sharing, spectrum access and spectrum sensing related to MAC and PHY layers. The upper protocol layer performs the operations of CR capabilities and the QOS issues, decision-making and monitoring functions could be done in the transport, application and network layer. Issariya studied and explain the CR network's performance issues of the transport layer. Chowdhury, Lee and Akyildiz defined the open research issues, various key challenges and concern performance which had appeared in the transport layers in Cognitive Radio Ad-Hoc Networks (CRAHNs).

According to Chowdhury, Lee and Akyildiz the connectivity in Cognitive Radio Ad-Hoc Networks is also spectrum dependent, which means the disconnection can be detected by spectrum handover or presence of primary users. Hence, this disconnection is detected and addressed through several innovative approaches. The main distinction of the traditional routing protocol is that the CR based routing protocol controlled the functions of primary users and its service interruption losses to establish the best routes.

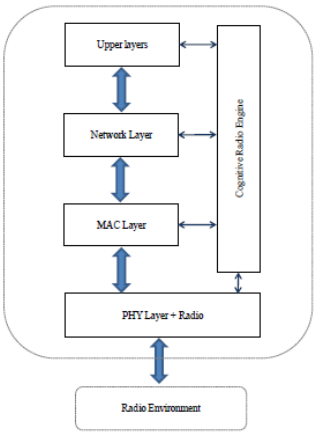

Figure 3 : Generic Cognitive Radio Architecture.

In cognitive radio networks the secondary users not have the rights to forward packets during sensing. So, the sensing function can be considered at the transport layer to avoid the pocket losses and excessive re-transmissions on the paths with each node in sensing state, particularly the interaction between MAC and transport entities and multi-hop distributed networks. Generally, the transport protocol needs to be spectrum-aware in CR scenarios and also require latest algorithms. Chowdhury, Lee and Akyildiz illustrate the TCP-based protocol for Cognitive Radio Ad-Hoc Networks and the main aim behind this approach is to address the transport layer challenges in Cognitive Radio Ad-Hoc Networks (CRAHNs).

III. Classification of Spectrum Sensing Techniques

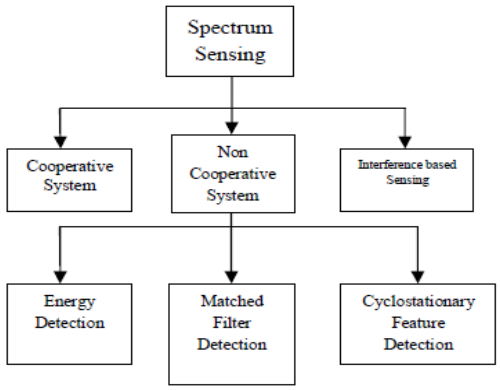

Figure 4 : Spectrum Sensing Techniques

a) Primary Transmitter Detection

This section describes the several primary transmitter detection techniques. They are

i. Energy Detection.

ii. Matched Filter.

i. *Energy Detection:* this technique not utilizes the previous information of primary signal energy.

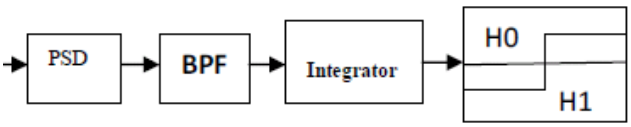

Figure 5 : Block Diagram of Energy Detection

Where H0 = Absence of User.
H1 = Presence of User.

The above figure represents the block diagram of energy detection. In this energy detection technology the signal is passed through band pass filter with W bandwidth and it is integrated over different time intervals. To detect the existence of absence of the primary user the integrator block output is compared with the predefined threshold value. This threshold value is variable or fixed this could be depends on the channel condition.

$y(k) = n(k)$..... H0

$y(k) = h * s(k) + n(k)$..... H1

Where $y(k)$ = sample to be analyzed at each instant k.

$n(k)$ = noise of variance $\sigma 2$.

The $y(k)$ allows the received samples sequence i.e. $k\epsilon\{1, 2....N\}$ 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 expected energy of the received signal and v is preferred for the noise variance i.e. denoted as $\sigma 2$. But, ED escorted by few disadvantages they are:

- ED cannot be used to discover the spread spectrum signals.
- Detection performance is subject to the precariousness of noise power.
- Sensing time taken to achieve a given probability of detection may be high.

ii. *Matched Filter*

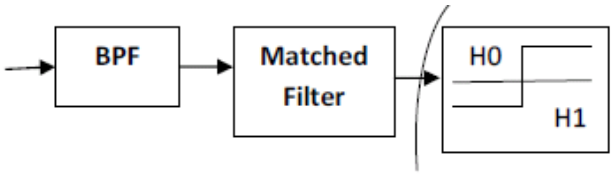

Figure 6 : Block Diagram of Matched Filter

Where H0 = Absence of User.

H1 = Presence of User.

Matched filter is also called as liner filter this could be designed to maximize the output signal to noise ratio for a given input signal. This filter detection can applied due to the secondary users has previous knowledge of primary users. The correlation is equal to function of matched filter in which the unidentified or new signal is curl with filter and the impulse response is time shifted and mirror version of a reference signal. Matched filter operation is expressed as:

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

Where 'x' = unknown signal

'h' = impulse response of matched filter

Matched filter detection process useful for the knowledge from the primary users is known to the cognitive users.

Advantages: the detection of matched filter is taking less time because it needs only O (1/SNR) samples to meet a given probability of detection constraint. However, the matched filter detection is best detection in stationary Gaussian noise because of the primary user signal is recognized to the cognitive radio user.

Disadvantages: matched filter detection process needs a previous knowledge of each primary signal. If matched filter not working properly then it gives poor information to the users. The major disadvantage of this matched filter is to every time the cognitive radio require devoted receiver for all types of primary user.

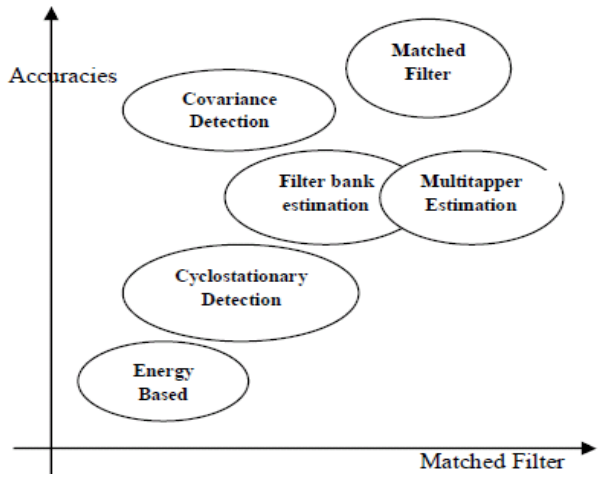

Figure 7 : Sensing accuracy and complexity of various sensing methods

b) Cooperative Techniques

Decentralized Uncoordinated Techniques: in this technique the Cognitive Radio will detects and vacate the channel independently, it could be done if the primary user find the channel without informing the other users. Compared to coordinated technique this technique don't have any disadvantages because in this technique the CR users will experience at poor channel recognition and discover the channel incorrectly thus it causing interference at the primary receiver.

Centralized Coordinated Techniques: this technique has the cognitive radio controller. This controller gives the information about the detection of cognitive radio in the presence of primary user. Therefore, by using broadcast method the controller provide the information to all cognitive radio users. This information supply procedure categorized into two types they are:

- Totally cooperative technique: in this technique nodes are helps to communicate each other's knowledge and to sensing the channel.
- Partially cooperative technique: in this technique the network nodes useful only for sensing the channel.

Decentralized Coordinated Techniques: this coordination technique strengthening the cognitive radio network without the need of controller. This technique involved several algorithms such as clustering scheme or gossiping algorithms, where cognitive users meet to clusters, auto coordinating themselves. Cooperative spectrum sensing improves the use of control channel and these channels can implement by underlying the UWB channel or detecting frequency channel.

Advantages of Cooperation: Cognitive users cooperating selflessly to sense the channel and this channel have more benefits such as channel Impairments like multipath fading, impose high sensitivity requirements inherently limited by cost and power requirements, shadowing and building penetration losses.

- *Disadvantages:* the cooperative technique has several disadvantages also like the Cognitive Radio user needs to execute sensing at periodic time intervals as sensed information become fast due to various factors like channel impairments and mobility etc.

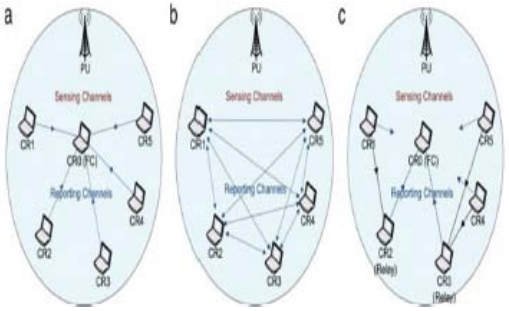

Figure 8 : a-Centralized Coordinated, b-Decentralized Coordinated and c-Decentralized Uncoordinated

Interference Based Detection: this section explains the interference based detection. In this detection method Cognitive users would operate in spectrum underlying approach.

Primary Receiver Detection: the primary receiver produces the leakage power of local oscillator through its RF front end and receiving the data from its primary transmitter. This method detects the presence of primary users by increasing low cost sensor node that is near to primary user's receiver detects the LO leakage power produces by the RF front end of the primary user's receiver which are within the communication range of CR system users. Then the local sensor intimate this sensed report to CR users. Hence, these users recognize the spectrum occupancy status and also identify the spectrum opportunities to operate CR users in spectrum overlay.

Interference Temperature Management: the major function of this Interference Temperature Management is to arrange an upper interface limit for specified frequency band in given geographic location. However, the CR users do not have the problem with interference while using the particular frequency band in particular area. The CR user transmitters manage their interference by varying their transmission power but it could be done by depending on their particular location with respect to primary users. Majorly this method focused on measuring interference at the receiver. The operating principle of this Interference Temperature Management is like an UWB technology where the CR users are permitted to synchronize and transmit synchronously with primary users. Low transmit power is controlled by the interference temperature level so as not to cause harmful interference to primary users.

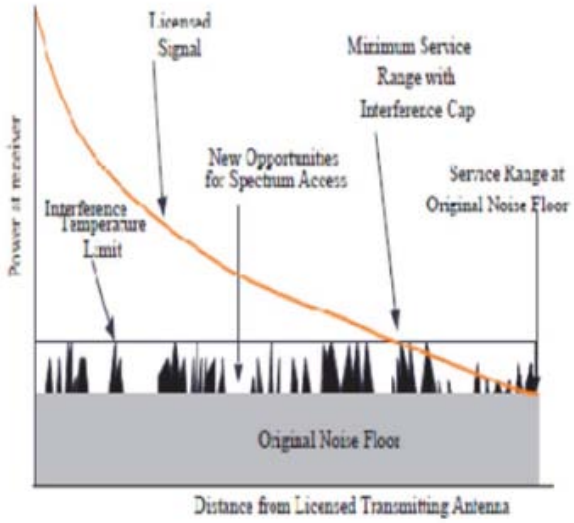

Figure 9 : Inference Temperature Model

IV. Issues in Spectrum Sensing

Channel Uncertainty: Because of fading or shading of the channel there will be uncertainties in the received signal strength which will lead to wrong interpretation. To avoid this Cognitive Radios must have high sensitivity so that he can differentiate between faded primary signal and a white space. If the fading is severe, a single cognitive radio cannot give high sensitivity so handle this we go for a set of cognitive radios which share their local measurements and collectively decide on the occupancy state of a licensed band.

Noise Uncertainty: The detection sensitivity can be defined as the minimum SNR at which the primary signal can be accurately detected by the cognitive radio and is given by

$\gamma min = PpL(D+R)$

N

Where N= Noise power.

Pp= Power Transmitted by Primary User.

D= Interference Range of Secondary User.

R= Maximum distance between Primary Transmitter and corresponding Receiver.

The noise power estimation is limited by calibration errors as well as changes in thermal noise caused by temperature variations. Since a cognitive radio may not satisfy the sensitivity requirement due to underestimate of N, γmin should be calculated with the worst case noise assumption, thereby necessitating more sensitive detector [10].

Aggregate Interference Uncertainty: If multiple Cognitive Radios are operating same in same licensed band which will lead to spectrum sensing will be affected by uncertainty in aggregate interference. Even though the primary user is out of interference range this uncertainty may lead to wrong detection so this uncertainty will create a need of more sensitive detector.

Sensing Interference Limit: There are two factors for this issue that is when an unlicensed user may not know exactly the location of the licensed receiver which is required to compute interference caused due to its transmission and the second reason is that if a licensed receiver is a passive device, the transmitter may not be aware of the receiver. So these factors need attention while calculating the sensing interference limit.

V. Conclusion

As the usage of frequency spectrum is increasing, it is becoming more valuable. So we need to access the frequency spectrum wisely. For this purpose we are using Cognitive Radio. In our paper we discussed about the most important technique that is Spectrum sensing and the issues involved in it to establish the communication using Cognitive radio. We also said about important the importance of cooperation between Secondary users to avoid interference.

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