Comparative Study of Different Non-Cooperative Techniques in Cognitive Radio

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***Abstract*- Wireless technology is expanding its domain and with it is growing the need for more frequencies for communication. Cognitive radio offers a solution to this problem by using the concept of Dynamic spectrum access instead of fixed spectrum allocation. Such radios are capable of sensing the RF spectrum for identifying idle frequency bands. It then transmits opportunistically so as to avoid interference with primary user over same band. In cognitive radio, intelligent spectrum sensing forms the major and most important part. Out of the various sensing techniques, we will give an overview of some of the prominent non-cooperative techniques. The paper deals with comparative study of these methods.**

***Keywords*- Cognitive radio (CR), Spectrum sensing, Primary User (PU), Secondary User (SU), Spectrum hole, Cognitive cycle**

I. INTRODUCTION

Radio spectrum is a limited natural resource. This resource in today's era has become one of the most valuable resources, with increase in use of wireless communication in almost every field of technology. In most of the countries specific frequency bands are allocated to users as licensed bands in exchange for fixed amount. The licensed bands are defined by frequency, transmission power, type of use etc. The process is known as fixed spectrum access (FSA) [2][10][15]. The authorised user of licensed band are known as primary user (PU) [2][3][8]. They can neither change the type of use nor transfer the right to other. This may lead to congestion of frequency band.

Thus there was a need to adopt dynamic spectrum access (DSA). This technique has been introduced to resolve the congestion problem. Cognitive radio [8][10][11] is the concept which is based on DSA [10][13][15][17]. This technique was introduced by Joseph Mitola in late 1990's [5][16]. It introduced the concept of opportunistic spectrum access (OSA) [15][17] and it automatically exploits unused or partially used band to provide new carrier for spectrum access. In CR the secondary user [2][3][8] has to continuously sense the environment to detect the presence of PU. PU has first priority on the assigned spectrum. As soon as SU detects that PU has become active it must switch to other available spectrum. CR uses the key feature of spectrum sensing for detecting the signal strength of available frequency and presence of PU. Spectrum sensing is used to find out spectrum hole [2][5][12][13] that can be utilized. Spectrum hole is defined as part of the spectrum that can be utilized by SU, which is a basic resource for CR. It is depicted as;

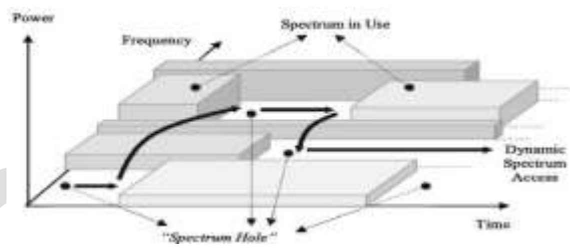


Fig.1 Spectrum hole

II. COGNITIVE RADIO

Cognitive radio is a solution to spectral congestion problem caused due to increasing number of users and scarcity of available spectrum. Cognitive radio was defined by FCC [2][3][4][5][18] as 'A radio or system that senses its operational parameters to modify system operation such as maximize throughput, mitigate interference, facilitate interoperability and access secondary market.' Cognitive Radio works on the principal of cognitive cycle [11][18].Cognitive cycle consists of various steps; Spectrum sensing, Spectrum decision, Spectrum sharing and Spectrum mobility. Cognitive cycle can be shown as below;

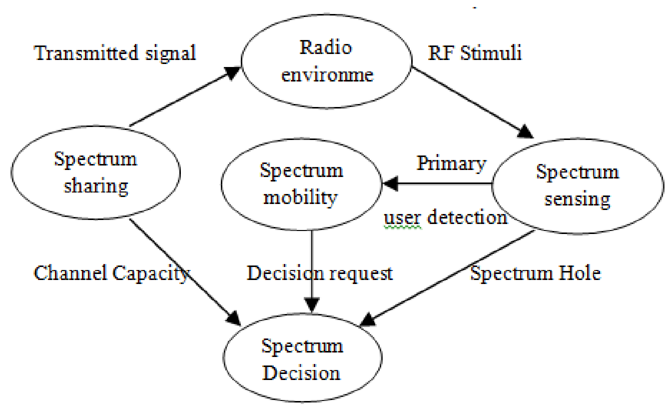


Fig.2 Cognitive cycle

Spectrum Sensing- This is the process of detecting unused or partially used spectrum. It makes the system aware of parameters related to radio channel characteristics, interference noise and transmit power [11][18].

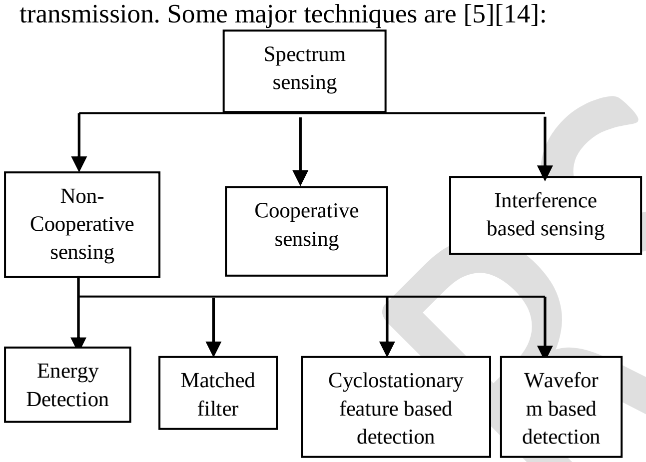
Spectrum decision- Based on the sensing result best available spectrum that meets user communication requirements is selected [11][18].

Spectrum sharing- It provides a fair spectrum scheduling method to users [11][18].

Spectrum mobility- In this step CR users exchange their frequency of operation [11][18].

III. SPECTRUM SENSING

Spectrum sensing [2][13] is the basic mechanisms employed by Cognitive radios (CR) to find the unused spectrum. Spectrum sensing is the task of obtaining awareness about the spectrum usage and existence of PU in a geographical area. The cognitive user can then decide whether it can use that frequency or not. It helps in determining the parameters that need to be adjusted inorder to avail the free or idle spectrum. By adjusting the parameters, this technique reduces the interference with PU. Spectrum sensing techniques are still in their early stage of development and number of methods has been proposed for identifying the presence of signal transmission. Some major techniques are [5][14]:



1. *Cooperative sensing*

The primary signal for spectrum opportunities are detected reliably by interacting or cooperating with other users. The method can be implemented in 2 ways. Either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the load smoothing algorithm or external detection.

2. *Interference based sensing*

In this type of sensing, CR system operates in an environment where the SU coexists with PU and is allowed to transmit at low power. The power is restricted by the interference temperature level so as not to cause harmful interference to primary users [12][14].

3. *Non-cooperative sensing*

It is also known as Transmitter detection method. This is called non-cooperative method as there is no cooperation or sharing among terminals. In his method CR user detect the presence or absence of PU through sensing by itself. The data obtained is used to decide on channel state that is idle or busy. Whereas in cooperative sensing CR shares its sensed data with others. The sensing outcome of others is utilized for decision. There are various methods for non-cooperative sensing. Some of the well-known methods are energy detector, matched filter, Cyclostationary based sensing and waveform based sensing [12][13][17].

a) Energy Detection: Energy detector based approach is also known as Radiometry or Periodogram. It is the most common way of spectrum sensing because of its low computational and implementation complexities. It is a type of non-coherent detection. In this process primary user detection is done by comparing energy of received signal with a predefined threshold and declares band as busy if measured energy is greater than threshold. The process can be depicted as follows [1][7][9][14][18],

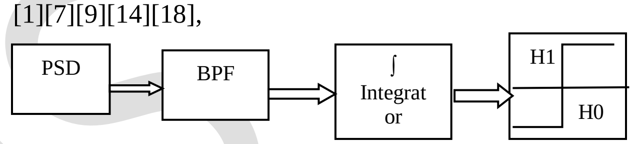


Fig.3 Block diagram of energy detector

In the above process the received signal is filtered with a band pass filter to select preferred bandwidth. Then it is squared and integrated over sensing intermission. The result which is the test static is obtained and is compared with decision threshold to test presence or absence of primary user. The test static or decision metric can be written as;

$$T(y) = \sum_{n=0}^{N} \big(y(n)\big)^2$$

T(y) is Energy detector test metric. λ is defined as the threshold which distinguishes between two test hypothesis.

$$H_0 : y(n) = w(n)$$

$$H_1 : y(n) = s(n)+w(n)$$

n→ number of samples , w(n) → AWGN noise, s(n) → signal to be detected

When, $T(y) > \lambda / H_1$

$T(y) < \lambda / H_0$

Hypothesis H_0 depicts absence of PU whereas H_1 depicts presence of PU.

Advantage- This method is more generic as receiver do not need to know any knowledge of PU and thus it can be used when PU information is not available [2][6].

Disadvantage- This method cannot differentiate interference from PU and noise. The performance is poor SNR is low [2][6].

b) Matched Filter: Matched filter method is a type of non blind spectrum sensing [10][16]. It is used to sense PU when information about transmitter working with parameters such as frequency, bandwidth, modulation type, pulse shaping and frame format are known.

Fig.4 Block diagram of matched filter based sensing

The signal received is passed through BPF. This will determine energy of received signal. The signal is then given to matched filter. The signal correlated with a time reversed version of itself. The signal is fed to comparator whose output is utilized to take decision whether signal is acceptable or not [3][7][14].

Advantage- This technique maximizes SNP of received signal and is best suited if CR has prior information of PU signal. Also another advantage is short time to achieve a certain probability of misdetection [6].

Disadvantage- If PU information is not accurate then matched filter operates weakly. CR users usually need to observe a wide spectrum band with multiple primary systems and thus, they need the receiver to estimate different types of PU signals which leads to high complexities in implementation and large power consumption [6].

c) Cyclostationary: This type of detection is done by exploiting Cyclostationary feature of received signal i.e. it exploits periodicity of received signal to identify PU. A signal is said to be Cyclostationary if its mean and autocorrelation are periodic function. It requires prior knowledge of signal. It can distinguish PU signal from noise and can be used at lower SNR by using the information embedded in PU signal that are absent in noise [5][7][9][13][14].

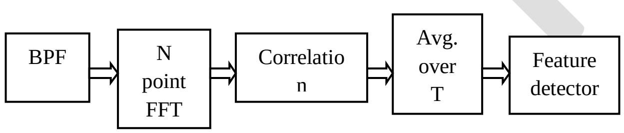


Fig.5 Block diagram of Cyclostationary based sensing method

Advantage- It typically allows difference among dissimilar signal or waveform or PU and noise. This is a result of the fact that noise is in a wide-sense stationary with no correlation while modulated signals are Cyclostationary with spectral correlation due to redundancy of signal periodicities [6]

.*Disadvantage*- The major drawback of this method is complexity of calculation as it deals with all frequencies in order to generate spectral correlation function [2].

d) Waveform based sensing: This type of sensing is also known as coherent based sensing. This is applicable to signals with known signal patterns such as preamble, midambles etc. Preamble is a known sequence transmitted before each burst or slot. Sensing is performed by correlating received signal with a known copy of itself. It requires short measured time. The decision metric can be constructed as [2],

$$M = \text{Re}\left[\sum_{i=1}^{N} n(i)\, s^*(i)\right]$$

The decision metric is compared to fixed threshold to determine if transmitted signal is detected. When the PU is transmitting the decision metric become,

$$M = \sum_{i=1}^{N} |s(i)|^2 + \text{Re}\left[\sum_{i=1}^{N} n(i)\, s^*(i)\right]$$

Where n(i)-noise present, s(i)- PU transmitted signal.

When PU is not transmitting then decision metric become,

$$M = \text{Re}\left[\sum_{i=1}^{N} n(i)\, s^*(i)\right]$$

Advantage- Number of samples required to form decision metric is less [3][6].

Disadvantage- The drawback of this method is that it requires transmitted signal to contain known pattern. The exact position of pattern may not be known. It calls for estimation of position which in turn, increases complexity [3].

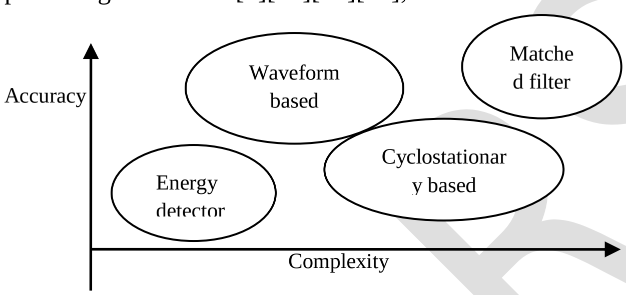
IV. COMPARISION BETWEEN VARIOUS NON-COOPERATIVE TECHNIQUES

After knowing about different methods of non-cooperative sensing, selecting a method for detection require some tradeoffs. Characteristics of PUs are main factor in selecting a method. Comparison based on certain characteristics is done in the following table:

Parameters	**Energy detector**	**Waveform based sensing**	**Matched filter**	**Cyclostationary based filter**
Accuracy in detection based on SNR value	Preferred if SNR is high but at low SNR the performance degrades.	Performs well at all SNR.	If receiver has prior knowledge of transmitter then it performs well at all SNR.	Overall performance is good at all SNRs.
Design pattern	Threshold selection forms an important deciding factor	Transmission pattern can be increased to improve accuracy.	Transmission characteristic can be appropriately chosen to improve accuracy.	Cyclostationary characteristic can be induced to improve accuracy.
Robustness	Information of transmitted signal is not required but it is not suitable for spread spectrum	Transmitted signal should contain, known pattern but exact position of pattern	Requires near perfect transmitted information at receiver.	Receiver must know transmitted signal fundamental frequency.

	signals.	of pattern may not be known at receiver.		
Complexity	Simple to impleme-nt but requires large number of samples to converge.	Requires small number of samples and also not so complex.	Requires small number of samples and is complex.	Requires small number of samples and is complex in nature.
Sensing time	Takes large sensing time to achieve a given probabili-ty of detection.	Takes compar-atively less time.	Requires less time to achieve high processing gain due to coherent detection.	Takes longer sensing time.

The above table describes various parameters on which we can choose a sensing method. Based on our priority of application, we may select any one of the given methods. Most of the time we consider the accuracy with respect to complexity of method under consideration. Based on the accuracy and complexity we can plot different methods on a plane as given below [2][13][14][18];



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