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# Analysis of Spectrum Sensing Techniques inCognitive Radio

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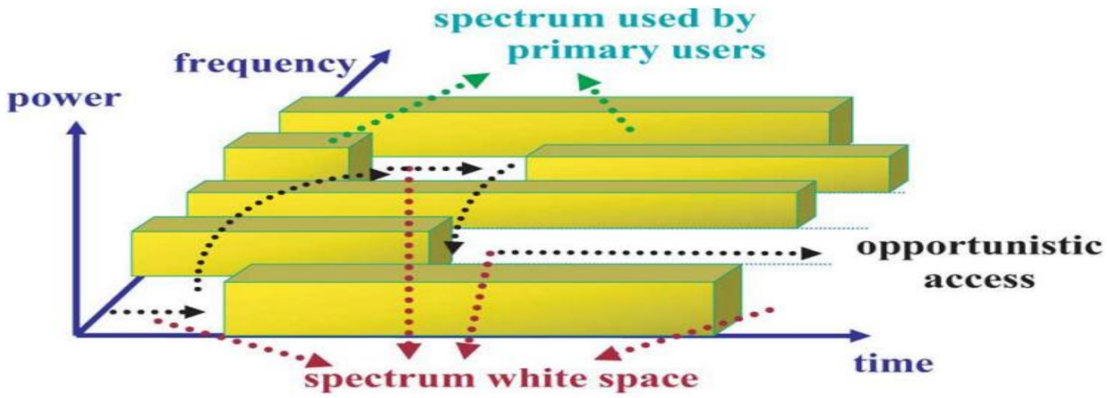
***ABSTRACT:*** *The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. However, a fixed spectrum assignment has lead to under utilization of spectrum as a great portion of licensed spectrum is not effectively utilized. Cognitive radio is a promising technology which provides a novel way to improve utilizationefficiency of available electromagnetic spectrum. Spectrum sensing is a basic approach and requirement to implement cognitive radio technology.In this paper, analysis of Cooperative, Non-cooperative and Interference Based spectrum sensingtechniques are presented. We also highlight the strengths, weaknesses, parameters concerned and feasibilities of these techniques with comparison among them. Various challenges and the parameters which can affect performance of these techniques are also discussed.*

***Keywords:****Cognitive, Cooperative spectrum sensing, Non-cooperative spectrum sensing, Interference Based Sensing.*

## I.INTRODUCTION

Cognitive radio (CR) concept can be applied to many advanced and challenging communication as well as networking systems. The word cognitive means pertained to cognition or the action or process of knowing. It also means the mental process of getting knowledge through thought, experience and the senses. Thus, incommunication systems CR defines the radio with ability to sense reserved, idle communication spectra which can be utilized by secondary users for other applications during its idle period [1],[2].CR maximizes throughput of spectrum to increase spectrum efficiency and facilitate interoperability by providing access to secondary user group for other applications [3]. Cognitive radio concept may be applicable at 400-800 MHz (UHF TV bands) and 3-10GHz.Moreover, for long range communication applications these frequency bands have good propagation properties.Cognitive radio systems offer opportunity to use dynamic spectrum management techniques to immediately utilize available local spectrum. Interms of occupancy, sub bands of the radio spectrum may be categorized as follows:

i) Whitespaces: These are free of RF interferers, except for noise due to natural and/or artificial sources.
ii) Gray spaces: These are partially occupied by interferers as well as noise.
iii) Black spaces: The contents of which are completely full due to the combined presence of communication and (possibly) interfering signals plus noise [4].The Figure 1 shows the WhiteSpaces and Used Frequencies in Licensed Spectrum.

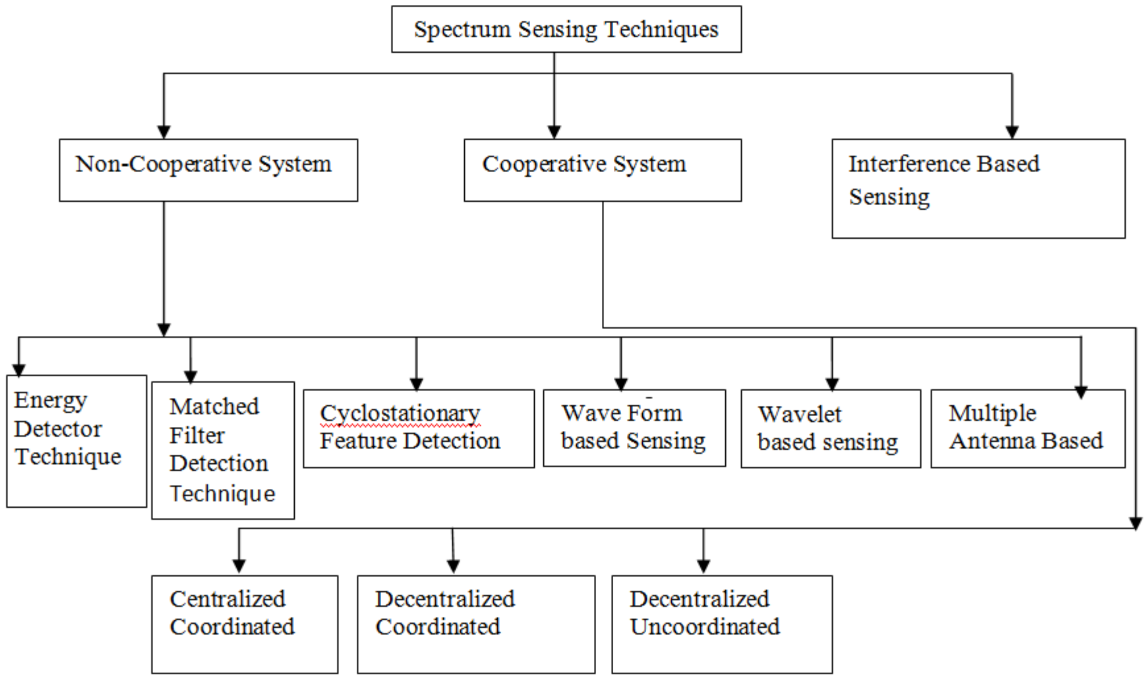



[Figure 1]: Illustration of White Spaces in Licensed Bands

When compared to all other techniques, Spectrum Sensing is the most crucial task for theestablishment of cognitive radio based communication mechanism.
This paper is organized as follows: Section II defines categorization of signal processing techniques for spectrum sensing. Section III presents most popular non-cooperative spectrum sensing techniques. In this section spectrum sensingtechniques are explained with their relative features and limitations. Cooperative sensing andits types are defined in section IV. In Section V Interference Based SensingTechniques are explained with their relative features and limitations and Section VI concludes this paper.

## II. SPECTRUM SENSING TECHNIQUES

Classification of most popular spectrum sensing techniques for implementation of CR technology is shown in Figure 2. This figurealso categorizes non-cooperative and cooperative spectrum sensingTechniques.




[Figure 2]: Classification of spectrum sensing techniques [5].

## III. NON-COOPERATIVE SENSING

Non-cooperative sensing techniques need detection of primary user signal by some parameter measurement and filtering. The location of primary user is not known.It is based on following hypotheses

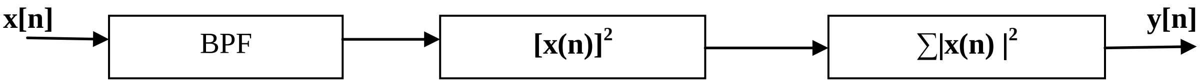
$$x(n) = \begin{cases} y(n) & Ho \\ s(n) + y(n) & H1 \end{cases}$$

In above equation H0 denotes absence of primary user and H1 shows its presence. y(n) and s(n) represents noise and primary user massage signal respectively. Popular non-cooperative Sensing techniques are:
3.1Energy Detector
3.2 Matched filter
3.3 Cyclostationary feature detection.
3.4Waveform Based Sensing
3.5 Wavelet Based Sensing
3.6Multiple Antenna Based Sensing

### 3.1 Energy Detector Technique

It is a straightforward detector that detects the whole energy content of the received signal over specific time length. it\'s the subsequent components:-
i)Band-Pass Filter (BPF):Limitsthe information measure of the received signal to the band of interest.
ii)Square Law Device: Squares every term of the received signal
iii) Summation Device:Add all the square values to calculate the energy.

A threshold worth is needed for comparison of the energy found by the detector. Energy bigger than the brink values indicates the presence of the first user.The principle of energy detection is shown in figure 3.1. The energy is calculated as

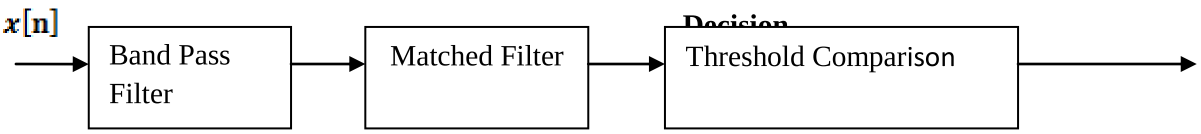



[Figure 3.1]: Principle of Energy Detection

Features:
(1) Energy detection method is popular due to its simplicity, ease of implementation and applicability. Noprevious information of the first user's signal needed. [6].
(2) It has low computational and implementation cost [6].
Limitations:
There are several limitations of energy detectors that might diminish their simplicity in implementation
(1) Threshold used for primary user detection is highly susceptible to changing noise levels. Presence of any undesired band possessing equal energy level might confuse the energy detector [6].
(2) Energy detector does not differentiate between primary user (PU) signals, noise and interference. So it cannot be beneficial to prevent interference [6].
(3) Energy detector is not useful for direct sequence, frequency hopping signals and spread spectrum signals [2].
(4) When there is heavy fluctuation in signal power so it becomes difficult to differentiate the desired signal [2].
(5) Compared to matched filter detection, energy detection technique requires longer time to achieve desired performancelevel [6].
(6)Problem associated with choosing a correct threshold for comparison functions.

### 3.2 Matched Filter Technique

The Matched Filter Technique is extremely vital incommunication because it is an optimum filtering technique that maximizes the signal to noise ratio (SNR).It is a linear filter and previous knowledge of the first user signal is extremely essential for its operation. Operation performed is adore a correlation. The received signal is convolved with the filter response that is the reflected and time shifted version of a reference signal. The figure 3.2 is outline of its function.

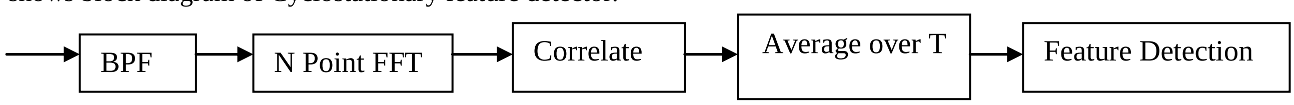



[Figure 3.2]: Principle of Matched Filter Technique.

Features:
(1) As Cognitive Radio user knows information of the licenseduser signal, matched filter detection requires less detectiontime due to high processing gain [7], [8], [9], [2], [3], [10].
(2) Matched filtering needs short time to achieve a certain probability of false alarm or probability of missed-detection [8], [3].
(3)Optimum detector it maximize the SNR ratio.
Limitations:
(1) It requires a prior knowledge of every primary signal [7].
(2) CR needs a dedicated receiver for every type of primary user [7].
(3) Cognitive radio needs receivers for all signal types; the implementation complexity of sensing unit is impractically large [8].
(4) Matched filtering consumes large power as various receiver algorithms need to be executed for detection [8].

### 3.3 Cyclostationary Feature Detection (CFD)Techniques

It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, thesecyclostationary signals exhibit the features of periodic statistics and spectral correlation, which isnot found in stationary noise and interference [11].The figure 3.3 shows block diagram of Cyclostationary feature detector.

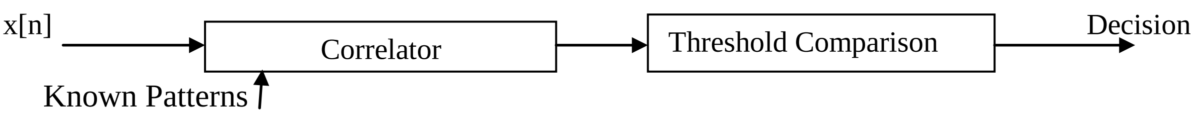



[Figure 3.3]: Block diagramof Cyclostationary feature detector [12]

Features:
(1) Cyclostationary feature detection performs better than Energy detection technique in low SNR regions [7], [9], [10].
(2) It is not affected by noise uncertainties. It is robust to noise [8], [9], [10].
(3) Frequency and phase synchronization of signal is not required.
Limitations:
(1) CFD requires long observation time, high sampling rate and higher computational complexity [8].
(2) CFD also requires the prior knowledge of primary user signal [8].
(3) There are possibilities of sampling time error.
(4) Since all the cycle frequencies are calculated that the machine complexness is above energy detector.

### 3.4 Waveform Based Sensing Technique

This type of sensing makes use of Preambles, pilot carrier and spreading sequences .These square measure other to the signal advisedly as data of such patterns facilitate in detection and synchronization functions. Preambles square measure set of patterns that square measure sent simply before the beginning of the data sequence whereas mid-ambles square measure transmitted within the middle of knowledge. The additional the lengths of these glorious patterns, additional are going to be the accuracy of the detection. The figure 3.4 highlights the most purposeful units of detector. The received signal is correlated with the celebrated patterns. The output of the correlator is compared with a threshold. In case the received signal is from the first users then it should have the celebrated patterns and so the correlation are going to be quite the edge or the case are going to be opposite just in case of noise.




[Figure 3.4]: Waveform Based Sensing Method outline

Features:
(1)The Sensing time needed for the waveform based mostly detector is low as compared to energy detector.[13]
(2)It’s additional reliable than energy detector.
Limitations:
(1) Higher accuracy needs a extended length of the proverbial sequences which ends up in lower potency of the spectrum.[13]

### 3.6 Wavelet Based Sensing Technique

A transition in frequency of an indication leads to edges within the frequency spectrum. This property may be terribly useful in detection algorithms. The waveband is sub-divided into variety of sub-bands every characterized by its own changes in frequency. The moving ridge rework is completed on these sub-bands to assemble the data regarding the irregularities or transitions. Moving ridge rework is applied and not standard Fourier rework as moving ridge rework offers the data regarding the precise location of the various frequency location and spectral densities. On the opposite hand Fourier rework is merely ready to show the various frequency parts however not the placement.The working principle [4] is illustrated in figure 3.5.the complete frequency vary is split into sub-bands. Rippling rework is applied to every of those sub-bands. The spectral densities of all the sub-bands are hunted for edges that represent transition from empty to occupied band. The presence of a grip indicates the presence of primary user within the band

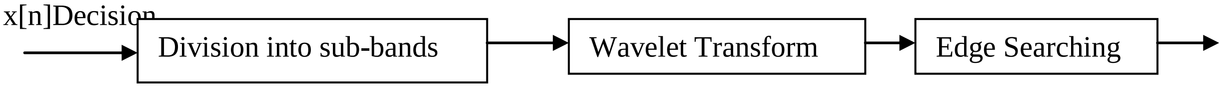



Figure 3.5: Principle of Wavelet Based Sensing

Features:
(1) Implementation price low as compared to multi-taper cost primarily based sensing technique.[13]
(2)It will simply adapt to dynamic Power Spectral density (PSD) structures.[13]
Limitations:
(1) So as to characterize the whole information measure higher sampling rates is also needed.[13]

### 3.6 Multiple Antenna Based SensingTechnique

Wireless transmissions via multiple transmit and receive antennas, or the thus referred to as multi input multi output (MIMO) systems have gained sizeable attention throughout recent times. MIMO systems typically use sensing schemes supported the Eigen values [14].In order to perform sensing for MIMO systems 2 basic steps are followed:-

Step-1:Planning of the check statistics that is obtained exploitation the chemist values of the co-variance matrix of the sample values. During this technique two algorithms are typically used, one being the utmost chemist worth detection and therefore the alternative being condition range detection.

Step-2:Account of the change density perform (PDF) of the check statistics or chemist values so sensing performance is quantified

Features:

(1) It does not need previous information of the received signal characteristics.[13]

(2) Since identical signal is received through multiple ways the noise power uncertainty is removed. [13]

Limitations:

(1)Use of multiple antennas will increase the value of the detector[13]

(2)The Quality of detector is additionally exaggerated. [13]

## IV.COPERATIVE SENSING TECHNIQUES

High sensitivity requirements on the cognitive user can be alleviated if multiple CR users cooperate in sensing the channel. Various topologies are currently used and are broadly classifiable into three regimes according to their level of cooperation [15][16][17].Cooperative sensing techniques: a-Centralised Coordinated, b-Decentralised Coordinated, and c-Decentralised Uncoordinated.

### 4.1 Decentralized Uncoordinated Technique

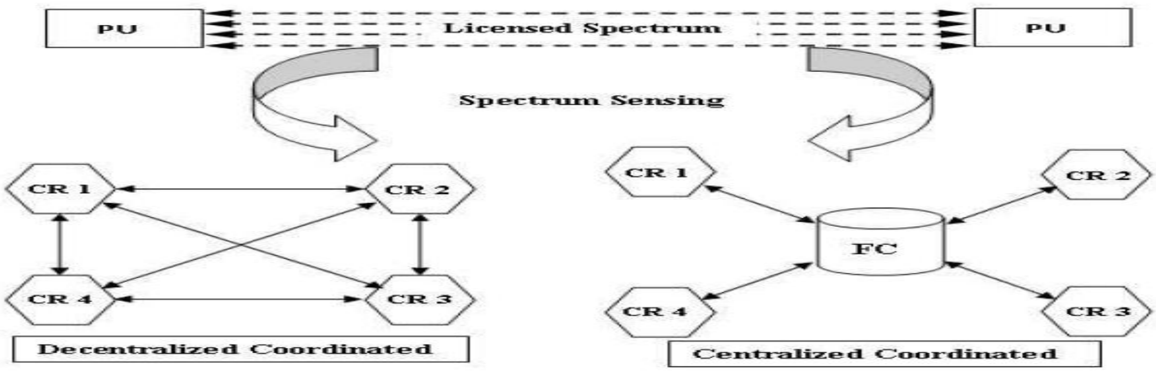
Each CR user performs channel detection independently and does not support or share its information with other CR users [9].

### 4.2 Centralized Coordinated Technique

This technique designates a CR controller which is called fusion centre (FC). It is in strong connectivity with its nearby CR users inits range. FC selects desired frequency band and inform all CR in network to perform local sensing. CR user in network detects idle channel or primary user; inform to CR controller which shares thisinformation with all other CR users in network [9], [2], [18].

### 4.3 Decentralized Coordinated Technique

It does not require any CR controller or FC. Each CR user works as FC in network and provides coordination to other CR users [9]. It is also called distributed cooperative sensing technique.




[Figure 4]: Cooperative Spectrum Sensing Techniques. [22]

The Figure 4 shows graphical representation of decentralized and centralized coordinated methods of cooperative spectrum sensing. In coordinated cooperative technique fusion centre (FC) is coordinating with 4 CR sensors while in uncoordinated technique all 4 CR sensors are connected with all the other CRs in network without existence of central fusion centre.

Features:

(1) Cooperative sensing decreases missed detection and false alarm probabilities [8].

(2) It solves hidden primary user problem and also decreases sensing problems [8].

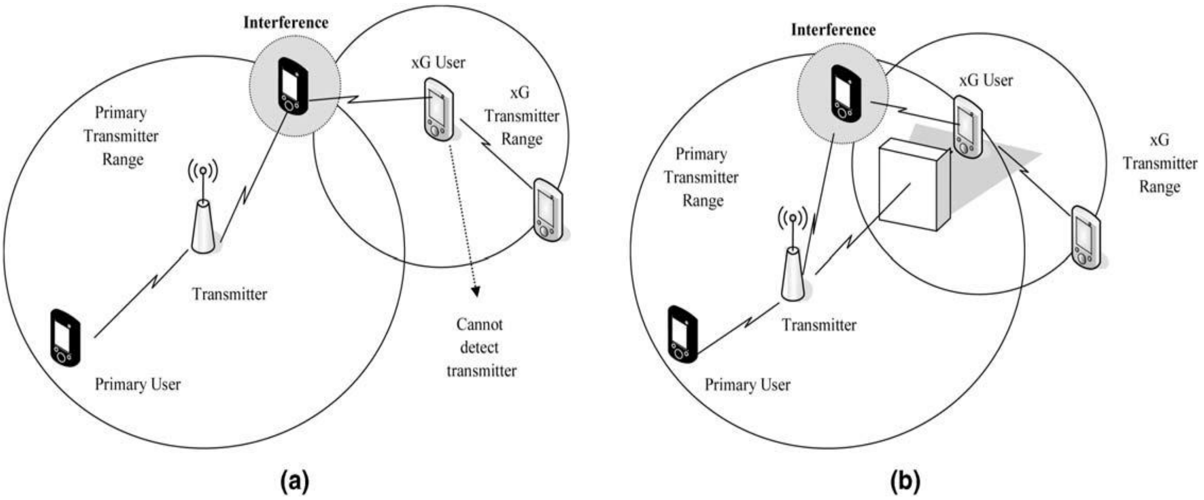
(3) It provides higher spectrum capacity gains than local sensing [8].

(4) It requires less sensitive detectors, which result in flexibilities, reduced hardware cost and complexities [19].

Limitations:
(1) Combining sensing results of more than one CR users havingdifferent sensitivities, is a difficult task [2].
(2) This technique requires a control channel to convey informationamong all CR users [2].

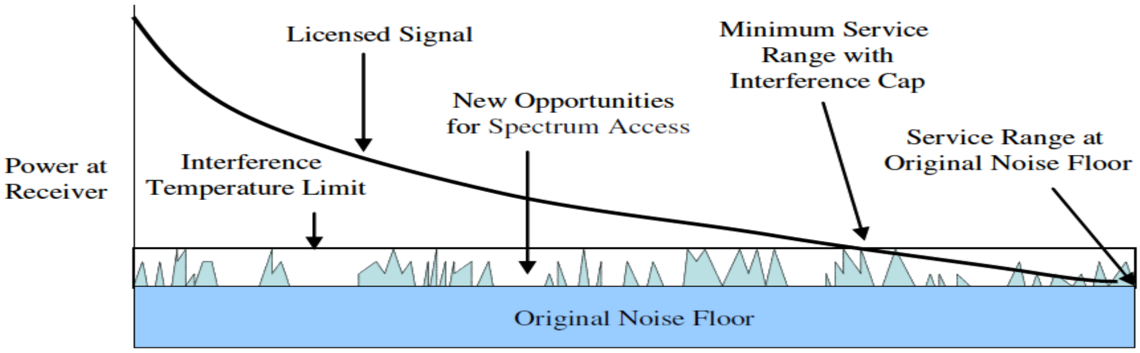
## V. INTERFERENCE BASED SENSING

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 emissions and location of individual transmitters. However, interference actually takes place at the receivers, as shown in Figure. 5.1 (a) &5.1 (b).[20]




[Figure 5.1]: Transmitter detection problem :(a) Receiver uncertainty & (b)shadowing uncertainty.[20]

A new model for measuring interference, referred to as interference temperature shown in Figure 5.2 has been introduced by the FCC [21].




[Figure 5.2]: Interference temperature model [21].

The model shows the signal of a radio station designed to operate in a range at which the received power approaches the level of the noise floor.

Feature:
(1) As additional interfering signals appear, the noise floor increases at various points within the service area, as indicated by the peaks above the original noise floor.[20]
(2)The interference temperature model accounts for the cumulative RF energy from multiple transmissions and sets a maximum cap on their aggregate level. As long as xG users do not exceed this limit by their transmissions, they can use this spectrum band.[20]
Limitations:
(1) The interference is defined as the expected fraction of primary users with service disrupted by the xG operations.[20]
(2) This model describes the interference disrupted by a single xG user and does not consider the effect of multiple xG users.[20]
(3) If xG users are unaware of the location of the nearby primary users, the actual interference cannot be measured using this method.[20]

(4) CR users do not perform spectrum sensing for spectrum opportunities and can transmit rightWay with specified pre-set power mask.[10]
(5) The CR users can not transmit their data with higher power even if the licensed system is completely idle since they are not allowed to transmit with higher than the pre-set power to limit the interference at primary users.[10]
(6) The CR users in this method are required to know the location and corresponding upper level of allowedtransmit power levels. [10]

## VI. CONCLUSIONS

In this paper, we discuss about three spectrum sensing techniques of cognitive radio such as cooperative, non-cooperative and interference based sensing.The main potential advantages introduced by cognitive radio are improving spectrum utilization and increasing communication quality. A novel approach to fulfil these requirements is to use CR concept.Cyclostationary feature detection shows the better detection performance as compared with the matched filter and energy detection techniques. We also said about important the importance of cooperation between Secondary users to avoid interference.Cooperative spectrum sensing raises the strength of cognitive radio network by combining efforts of multiple cognitive sensors. Most popular techniques for spectrum sensing are analysed in this paper.

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