# Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey

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***Abstract*—**Cognitive Radio is a one of the recent emerging technologies, with a wide range of potentialities in network that support and facilitate an effective, efficient and elastic used of the inoperative radio spectrum. It has the capability of systematically and intelligently senses a frequency band and makes use of unfilled vacant spectrum. The sophisticated sensing technique which enables wireless devices to access the radio spectrum and decide whether the network is being used by the designated users, otherwise it will utilize the opportunity and take charge. Cognitive Radio cannot make any changes to the network and automatically detects when the original user arrives and vacate wisely without causing any harmful intrusion. Alternatively, cognitive radio seems a way out to tackle the scars of the radio spectrum, which can be achieved by proper management and applying different techniques, such as, spectrum sensing, spectrum decision, spectrum sharing, dynamic spectrum and how the transmission/receiving of the spectrum. There are many significant features that make the present cognitive radio far ahead of the ordinary or conventional techniques. Present technique is faster and most likely accurate, spectrum sensing is one of them and this paper will review the available novel technique on different sensing technique, its applications, principles and future direction.

**Keywords-component; Radio Spectrum; Cognitive radio; Dynamic Spectrum; Spectrum Sensing; Spectrum sharing**

## I. INTRODUCTION

For decades, the used wireless network technology has been dramatically increasing across the globe and the need for more research on how to improve the economy usage of the wireless network has been the driving force of the present day technology [1, 2]. Although the wireless frequencies are primarily controlled by Federal Authorities, they issued license for usage of the spectrum that can only be used by the dedicated users or Primary Users. However, the frequency bands are labelled and have a wide coverage, often remain unutilized [3, 4]. Cognitive Radio (CR) uses a wise and intelligent technique to gauge and access the adamant spectrum band resources that are not in use in the environment. Obviously, the Primary users are licensed users that have the full and autonomous power to use the frequency band any time they need without any obstruction. On the other hand, the Secondary users sometime called opportunity users also make use of the same frequency band to transmit and receive signals, subject to the absence of the licensed users. The Secondary users will wisely and intelligently sense the idle spectrum band in the environment and make use of it, avoiding any interference with the licensed users [5, 6].

One of the most significant achievements of CR is the systematic detection and distinguishing the active or the operating band, from the inoperative band in a wide spread frequencies spectrum in certain environments and use them appropriately. Likewise, it gauges and detects the available or empty hole efficiently and accurately. However, the spectrum sensing is susceptible to poor weather, disturbance, noise, etc. In addition, the significance of the CR is not only limited to detecting and occupying the spectrum. Rather, it efficiently, and accurately senses the empty spectrum and decide when and how to make use of it. Thus reducing overlapping of involuntary close frequencies. CRs are mainly designed to work and operate in a wireless connection with the limited scale environment and capacity; the spectrum access maintains its simplicity of operation to avoid any complication [5, 7].

In (2003), the recommended definition of Cognitive Radio by Federal Communications Commission stated "A cognitive radio (CR) is a radio that can change its transmitter parameters based on its interaction with the environment in which it operates" The interaction may comprise active communication with other spectrum users, It also includes passive detecting and decision taking inside the radio [8]. The following concept: spectrum sensing, sharing of spectrum, spectrum decision, and flexible/dynamic spectrum or spectrum mobility are used to achieve the maximum success and effective implementation of CRs. The above mention method facilitates the management time delay to achieve an accurate spectrum sensing and maximum proficiency in the utilization of the frequency spectrum, below in figure 1 is the depiction of the operation of the above mentioned technique in CR [3].

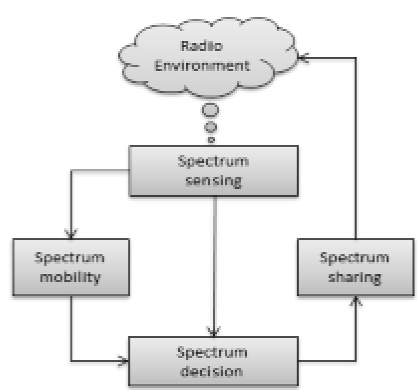


*Figure 1. Cognitive radio operation based* [7].

This research work discusses the novel approach of Cognitive Radio (CR) with emphasis on spectrum sensing techniques, it provides an overview of the conventional spectrum access in II, Spectrum Sensing technique is discussed

ISSN 2229-5518

in III and critical review of the major technique. IV is Management of CR. Some of the physical methods are described and classified in the work, also, the future direction, the present challenges in the CR and how to overcome them.

## II. General Overview of spectrum Estimation

Generally, the spectrum assessment or estimation can be subdivided into two classes; Direct/Frequency Domain Method and Indirect or Domain Method. The former is the conventional technique where the power of spectrum estimation can be generated by direct estimated signal. While the latter, is the evaluation of the estimated autocorrelation role. The power spectrum coverage can be achieved by using Discrete Fourier Transformation. Alternatively, Spectrum Estimation can also be a rift into; Parametric and non-Parametric technique. Parametric method is a classical method and modelling of signal which can be achieved by Auto Regressive Moving Average Method. It has the ability to differentiate advance sophisticated features. Shortcoming; lack of adequate and precise or exact account of signal at the initial or model amount to trivial outcome. In contrast, the non-parametric techniques are unpredictable and has no specific format, but striving hard to uncover adequate and suitable power spectrum estimation with previous awareness or familiarity of the existing method [5, 7].

Period gram is one of the popularly known technique for spectrum sensing that operate as non-parametric method and uses a randomly generated signal and various calculation method achieved the require outcome. However, fail to address some key problem such as leakage of data or lobe, low quality frequency. Various techniques to avert the threat are available which include; detecting the trade off, minimizing the inconsistency of power estimation [5].

## III. Spectrum Sensing Techniques

Researcher across the globe are making more effort to significantly improve the spectrum sensing technique, different proposed techniques can be used to achieve signal detection in cognitive radio [4]. The licensed frequency band is being issued to the Primary Users which in most cases remain unused with respect to time and constraint [8, 9, 10]. The spectrum techniques senses the surrounding or environment in a dynamic and automatic nature to enable proper operation adjustment of bands [10]. The spectrum sensing technique allows the CR easier detection, gauging or sensing of available unutilized spectrum holes in a certain environment without causing any disruption or damage to the primary users [2].

In addition, spectrum sensing must provide protection to the primary user to avoid overlapping. The protection can be ensured by making sure whether the primary user is active or not, when it detect that the PU is active it automatically jump to the next available hole as shown in the figure 2 below. Moreover, the secondary users cannot use an active spectrum hole. However, spectrum sensing is susceptible to very low signal in a noisy environment.

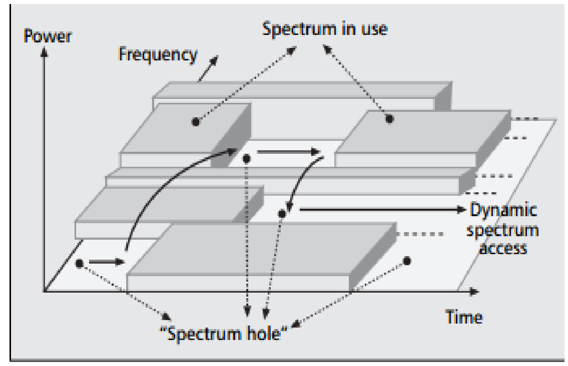


*Figure 2. An illustration of Spectrum holes according to [11].*

Furthermore, CR has the ability to decide how long a particular hole should be occupied. According to Khattab and Perkings in [12], all spectrums sensing must satisfy the following two conditions. First, the information gathered must be sufficient for the cognitive radio to be able to rely on the result. Secondly, the CR must be able to quickly track the temporal availability in the radio environment. However, implementation of the above conditions, require hardware specification. In addition, The CR requires to be observing it domain, which can be achieved with the help of hardware and software resources. The observation can be locally made and disseminated by various CR devices which can be discussed further in this research paper. According to [13] the spectrum sensing techniques can be classified in to four different groups, namely Coherent, Non-coherent, Narrowband and Wideband. These can be further subdivided into subgroups as shown in the figure below.

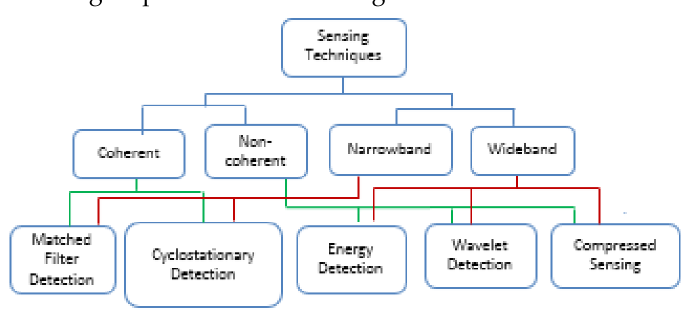


*Figure 3. Classification of Spectrum Sensing Techniques [13].*

Coherent detection is previous knowledge of detecting spectrum signal and it requires the following features to perform the detection; Modulation type, modulation order, pulse shaping and packet format. Whereas the non-coherent is the opposite that did not require any prior knowledge. Rather, it requires a detector to sense sufficient information about the unutilized primary signal [13, 14, 15].

Narrow band spectrum has a narrow frequency range the name implies. While Wideband has a wider frequency range, which ranges from 100MGHz to several GHz [15]. Axell et al in [16] claimed that the wideband techniques increases the reliability of the CR networks. Wideband technique is recommended for utilizing the available frequencies in the UHF TV. In addition, the wider the frequency range the more spectral opportunities. Moreover, it requires a very high sample rate for high power consumption in analogue to digital converters A/D. According to De Vito in [11] the wideband spectrum has a problem of detecting and determining already occupied and the idle portion of the spectrum such that it is the problem arises while observing… partition {say P1, P2, P3, …, Pn} of frequency F. There exist at most a signal in each sub-band. It further classify and identify all the sub-band that is the active and inactive bands as depicted in figure 4 below.

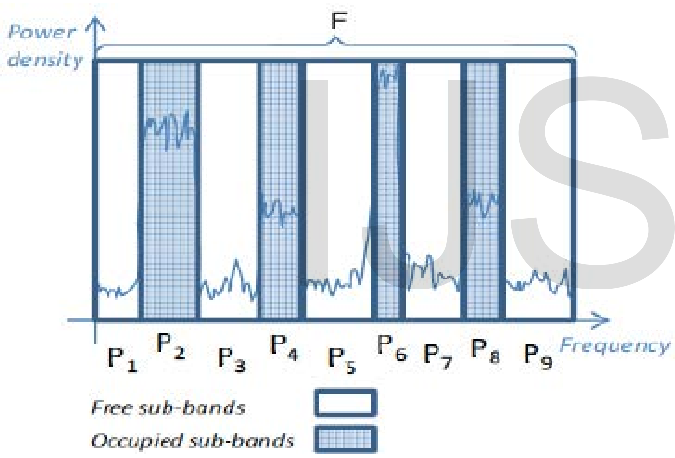


*Figure 4. Wideband spectrum sensing problem*

On the contrary, the narrowband enhanced sensitivity by lowering the noise flow. It uses a single binary decision technique made for the whole spectrum purposely to be used in narrowband domain [15].

In addition, wide band spectrum sensing can be classified into two classes; namely, Nyquist and sub-Nyquist wideband sensing. The former is receiving a digital signal taken over the Nyquist rate, while the latter processes the signal with sample rate below Nyquist rate. The Nyquist rate is a sampling rate and must be as twice as the size of the frequency signal to avoiding clashing or error. For instance, if the wideband signal has a frequency band of 4GHz, so the Nyquist rate should be 8GHz [17]. Consequently, the Nyquist rate is costly for future generation mobile networks. Because developing sampling hardware processes at a sufficiently higher rate, plus inventing efficient signal processing algorithm will be challenging and demanding to wideband spectrum sensing. Alternatively, a solution is proposed in which the wideband is divided into different narrow bands. Thus, each narrowband technique can be used each and every sub-band.

There are various techniques that can identify the existing signal in transmission, some identify, detect, and decide how the signal can be transmitted. Among the numerous spectrum technique, this part will give emphasis on the leading technique, their impact (both positively and negatively), challenges and some of their distinctions will also be covered.

These are;
- Energy Detection Technique
- Matched Filtering Detection Technique
- Cyclostationary Feature Detection Technique
- Multichannel Detection Technique
- Compressing Detection Technique
- Filter Sampling Detection Technique

### A. *Energy Detection Technique*

Energy Detection is one of the popularly known sensing technique that employ the use of optimum detection methods to detect the primary signal, especially when receivers fails to detect any signal [11] The energy detector Gauge, sense and make the availability of the primary signal by measuring the signal resolution or energy, provided that the threshold is greater than the calculated signal power. Implementation of energy detector is cost effective. However, it is susceptible to noise, especially when the signal is very low. Thus making it difficult to distinguish the primary signal with noise, [12].

### B. *Matched Filtering Detection Technique*

This is a constant Gaussian noise where the operation will be based on the previous generated information regarding the signal of primary user [11]. It uses previous information of the primary user and the accepted sense signal to realize the existence of a primary user signal, resulting to improve the performance of signal to noise ratio. Matched filtered technique reduce the time spent in the spectrum sensing to maximize accuracy and performance. Its disadvantage is the need of prior information [18], and required lower signal to noise ratio. It also employs the used of larger or wider spectrum frequency along with numerous primary users that needed different primary signal which, will make the computation difficult [10].

### C. *Cyclostationary Feature*

In cyclostationary modulation, signal is divided into two distinct parts, regular recurrence or in building periodicity and auto stationary detection technique, it can be attained by practical feasibility spectrum correlation function. The Cyclostationary feature technique enables the cognitive radio

ISSN 2229-5518

realize a particular primary signal that is secured from noise effect and temporal interference. The drawback includes, computational difficulty and the need for maximum time [11, 12].

### D. *Multichannel Detection Technique*

It is of paramount importance that a receiver should have a reliable estimate of the interfering temperature threshold to avoid noise floor in any licensed frequency transmission. The power spectrum of the interference temperature can be estimated using the multichannel spectrum detection technique with several numbers of sensors. This assists in moving the spatial variation of the radio frequency from one position to another. Thus describing the distinction between the variance and bias of the estimator. Therefore, provide a closely optimal performance estimation [19].

### E. *Compressing Detection Technique*

Wideband spectrum sensing can be easily realized with the help of compressing detection technique. This is because it has a very low utilization of spectrum [12]. According to De Vito et al in [15] Spectrum sensing in wideband requires high speed data conversion and very robust processing. Unlike the wideband, this technique can reduce high demand. Compressing Detection technique exploits that, the analog signal with double sided bandwidth can be sampled frequently below the Nyquist rate within a specific interval of time using a peculiar linear sampling [16]. Furthermore, this technique applies to a wavelet edge detection algorithm to the samples from analog-to-information (A/I) instead of the traditional analog-to-digital. The detection can be achieved using the compressed samples from A/I converter using minimum variance distortion less response estimator (MVDR) [12]. However, any defect in the design can easily affect the performance of the A/I converter [15].

### F. *Filter Sampling Detection Technique*

This technique demonstrated an approach of using filter sampling based on the concept of multicarrier modulation used as the basis communication technique. The spectrum sensing here can be performed by measuring signal power [5]. The multicarrier technique can be used as a filter bank, since it is achievable by averaging the output of several model filters at an equal frequency band. However, the multicarrier estimation technique is simplified by introducing one filter for each frequency band.

## IV. CHALLENGES IN SPECTRUM SENSING

### A. *Interference Temperature*

Lack of proper communication between the primary and cognitive radio lead to difficulty to the primary users to navigate to the exact position of their receivers. This remains a greater challenge for the researchers to do more in improving and developing the method that can properly address the temporal interference to the primary receivers [19, 12].

### B. *Channel Uncertainty:*

Channel fading may likely cause higher interference in CR. If the primary signal is suffering from being heavily shadowed or deep fading, then the secondary user may give wrong interpretations of the location of the primary which might likely result in interference. Therefore, CR needs to be sensitive in distinguishing a shadowed or faded primary user's signal from white space. However, this issue can be addressed by devising cooperative sensing technique, because single CR may not be able to achieve the required sensitivity [12, 21].

### C. *Sensing Interference Limit*

The net major problem here lies in the interference measurement from licensed receiver which is caused by transmissions from secondary users. Firstly, the secondary user may not aware of the location of the primary user which needed to calculate the cause of interference transmission. Secondly, if a primary user is inactive, the transmitter may not notice the licensed user. Therefore, the above mentioned factors require careful attention when computing the sensing interference limit [21].

### D. *Noise Uncertainty*

The detection sensitivity can be defined as the minimum signal to noise ratio at which the licensed signal is accurately detected with a probability of 0.99. The noise should be clear to calculating the required detection sensitivity, which is required to be estimated by the receiver. However, this is difficult to attain in practice. In addition, the estimation noise power is constrained by calibration errors and thermal noise caused by temperature variations. Since a CR may not satisfy the sensitivity requirement due to an underrated noise power, then it should be calculated with the least available noise assumption, thus necessitating a more sensitive detector [5].

### E. *Spectrum Mobility Issues*

The flexibility of spectrum in CR allows the secondary user to adjust the operation of spectrum with dynamism based on the spectrum conditions. Additionally, the flexibility intensifies novel type of handoff in CR networks, spectrum handoff procedures for different types of network layers stack must acclimatize to the channel bounds of the operating frequency.

Moreover, there is a need for transparent operation to the spectrum handoff and associated latency. Changing frequency of operation by the CR user will require a change

ISSN 2229-5518

in the operation parameters. Spectrum mobility management ensures the smooth and fast switch leading to minimal performance degradation during a spectrum handoff. One of the most important requirements of mobility management is the duration of a spectrum handoff, delivered by the sensing algorithm. Subsequently, when the information of the latency is obtainable, the continuing communications can be preserved with only minimum performance degradation [21].

## V. CONCLUSION

Cognitive radio is an economic method of utilizing the unused frequency band, before CR there were larger amount of unutilized spectrum holes, cognitive radio facilitates proper detection and used of spectrum holes with a wider need of more sophisticated communication technique. The literature in the research has extensively discussed the most commonly known signal processing technique which is Energy, Matched Filtering, Cyclostationary Feature, Multichannel, Compressing and Filter Sampling Detection Technique. Energy detector sense and make the availability of the primary signal by measuring the signal resolution or energy, provided that the threshold is greater than the calculated signal power. Whereas Matched filtered technique reduces the time spent in the spectrum sensing to maximize accuracy and performance.

In cyclostationary the modulation signal is divided into two distinct parts, regular recurrence or in building periodicity and auto stationary detection technique, it can be attained by practical feasibility spectrum correlation function. While in a multichannel technique power spectrum of the interference temperature can be estimated using the multichannel spectrum detection technique with several numbers of sensors. This assists in moving the spatial variation of the radio frequency from one position to another. Furthermore, compressing detection technique exploits that, the analog signal with double sided bandwidth can be sampled frequently below the Nyquist rate within a specific interval of time using a peculiar linear sampling. But the filter sampling detection technique demonstrated an approach of using filter sampling based on the concept of multicarrier modulation used as the basis communication technique.

Challenges facing the CR were also highlighted which include but not limited to Noise Uncertainty, Spectrum Mobility problem, Sensing Interference Limit, Channel Uncertainty and Interference temperature. In addition, table 5 below distinguishes and highlight the advantages and disadvantages of different signal processing techniques.

| Techniques | Advantages | Disadvantages |
|---|---|---|
| Matched Filtering | High performance and cost effective implementation | Need Primary User's previous information |
| Energy Detector | Need no previous information and low implementation budget | Susceptible to noise and Difficulty to distinguished PU and SU |
| Cyclostationary feature | Useful for low signal noise ratio area and free from interference | Need some previous information and High implementation cost |
| Multichannel | Small amount of sample and remain strong against model disparity | Need numerous channel for sample |
| Compressing | Small amount sample and affordability of signal | Deficient design |
| Filter Sampling | Small amount of sample, but wide and flexible coverage | Computational complexity |

*Figure 5. Advantages and disadvantages of different signal processing technique*

Conclusively the CR may play an important role in the near future. However, there are diverse open research challenges associated with spectrum sensing which require to be addressed, these include but not limited to Interference Temperature Measurement, Hardware Requirements, The Hidden Primary User Problem, Spectrum Sensing in Multi User Network, Detection Capability, Spread Spectrum Primary Users and Sensing Time.

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