IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 11, Issue 4, Aug-September 2023
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Cooperative Spectrum Sensing Using 5G Cognitive Radio Network

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Abstract:

In this paper, we propose a simulation methodology for spectrum sensing technique. For cognitive radio networks to operate efficiently, secondary users (SU) should be able to exploit the radio spectrum that is unused by the primary network. A critical component of cognitive radio is thus spectrum sensing This paper describes a simulation framework that can be used to evaluate spectrum sensing by single unit (local sensing) and multiple SU's (collaboratively). The detection performance is described through substantial simulation using MATLAB simulation tool. This report discusses the algorithm framework of local sensing using energy detection.

This paper carried out local sensing phase using energy detection to scan the complete available channel set from 1700MHz-2400MHz with resolution of 8MHz. Similarly, cooperative spectrum sensing (CSS) phase is carried out after local sensing phase.

Keywords: *Cognitive radio networks, cooperative spectrum sensing, hard and soft decision fusion, energy detection, feature-based sensing.*

1. INTRODUCTION

Presently, due to increase in the number of users in wireless networks against limited radio spectrum, problems have arisen in spectrum management. The radio spectrum is underutilized in the static approach to spectrum management. The conventional allocation of the spectrum is based on proper utilization of the spectrum. However, it is inflexible because each wireless operator must be given a license to operate at a certain frequency. Above all, it is becoming difficult t o find vacant bands in the radio spectrum to deploy new services, as most portions of the spectrum have already been allocated. To overcome this problem, it has become necessary to find out technological means for improved utilization of the spectrum to create opportunities for dynamic spectrum access. Currently, the 'Cognitive Radio' (CR) technology is the best technology available to improve the spectrum utilization in wireless communications. The CR is used to provide reliable communication between the users at any time by effectively utilizing the spectrum. The key function of the CR is the spectrum sensing that opportunistically detects the unutilized spectrum, which is licensed to the primary user (PU). Some of the sensing methods are matched filter, energy detection, and cyclo-stationary feature detection.

2. Literature Survey

[1] This paper proposes a cooperative spectrum sensing optimization algorithm for energy-harvesting cognitive radio networks (CRNs). The proposed algorithm aims to maximize the sensing throughput while satisfying the energy harvesting constraint. The paper provides a comprehensive performance analysis of the proposed algorithm using mathematical analysis and simulations.

[2] This paper proposes a new CSS optimization algorithm for energy harvesting CRNs. The proposed algorithm can adaptively adjust the sensing time and decision threshold based on the energy availability and the channel conditions. The paper provides a comprehensive performance analysis of the proposed algorithm using mathematical analysis and simulations.

[3] This paper proposes a hybrid spectrum handoff approach to improve energy efficiency in cognitive radio networks by using cooperative spectrum sensing. The paper focuses on the problem of energy consumption in the cognitive radio network and how to reduce it by developing an energy-efficient handoff mechanism. The authors used a hybrid approach that combines centralized and distributed spectrum

sensing to detect the presence of primary users. The proposed approach uses a threshold-based technique to determine when a handoff should occur. The simulation results show that the proposed approach outperforms other traditional approaches in terms of energy efficiency.

[4] This paper provides an overview of cooperative spectrum sensing in cognitive radio systems. The paper describes the basic concepts of cooperative spectrum sensing and the various sensing techniques used in cognitive radio systems. The authors also discuss the challenges and issues related to cooperative spectrum sensing and the possible solutions to address them. Additionally, the paper presents several cooperative spectrum sensing algorithms and protocols that have been proposed in the literature.

[5] This paper provides a comprehensive review of the cognitive radio technology and its potential applications in 5G wireless communication networks. The authors discuss the challenges associated with 5G wireless communication networks, including spectrum scarcity, energy efficiency, and reliability. They also discuss the role of cognitive radio technology in addressing these challenges, including the use of spectrum sensing, spectrum sharing, and spectrum management techniques. The paper also provides an overview of the various cognitive radio architectures and their applications in 5G wireless communication networks.

[6] This paper present a study on cooperative spectrum sensing and hard decision rules for cognitive radio networks. The authors discuss the importance of cooperative spectrum sensing in cognitive radio networks and the challenges associated with it. They also present a survey of the existing cooperative spectrum sensing techniques and their performance evaluation. The paper also provides a comparison of the different hard decision rules used in cooperative spectrum sensing and their effectiveness in improving the detection performance. The authors conclude that the cooperative spectrum sensing technique can significantly improve the detection performance of cognitive radio networks and that the selection of an appropriate hard decision rule is critical for achieving optimal performance.

3. Spectrum Sensing

The spectrum sensing is the main feature of the CR, it helps to avoid the interference between the primary user and the secondary user. CR technology is being used to provide a method of using the spectrum more professionally. Cognitive radio spectrum sensing is divided into two parts:

A. Non-cooperative Spectrum Sensing:

In this type of sensing each secondary user independently detects the presence or absence of a primary user signal in a given frequency band without any collaboration with other users. Each secondary user makes its own decision based on its own sensing data and reports the decision to a central node. Non-cooperative spectrum sensing can suffer from low accuracy and high false alarms due to the lack of collaboration between secondary users.

B. Cooperative Spectrum Sensing:

In this type of sensing multiple secondary users collaborate to detect the presence or absence of a primary user signal in a given frequency band. The sensing results from each user are then combined at a central node to make a final decision. This technique can improve the accuracy and reliability of spectrum sensing by reducing false alarms, increasing coverage area, and enhancing the robustness of spectrum sensing in dynamic and noisy environments.

4. Energy Detection

Energy detection is a common signal detection approach which is referred in classical literature as radiometry. Radiometry is a set of techniques for measuring electromagnetic radiation including visible light. Since we are dealing with spectrum, the analysis is termed as Spectro radiometry. It provides the periodogram which is an estimate of power spectral density of a signal. Power spectral density is the power carried per unit frequency.

When the spectral environment is analysed in frequency domain and power spectral density (PSD) of observed signal is estimated, this approach is termed as Periodogram. In this method, first received primary signal is prefiltered with a band pass filter (BPF) of bandwidth 'W' to select the desired frequency band. Filtered signal is then squared and integrated over observation window of length 'T'. This gives an estimated energy content of the signal which is then compared with a threshold value depending on noise floor to decide about the presence of primary user signal in the scanned sub-band.

The detection problem is analysed as a binary hypothesis model as

$$X(t) = n(t) \qquad 0 < t \leq T \quad H_0$$

$$X(t) = h*s(t) + n(t) \qquad 0 < t \leq T \quad H_1$$

Where x(t) is the signal received by CR during observation window T, n(t) represents the additive white Gaussian noise (AWGN). s(t) represents the transmitted signal from, primary user which is to be detected and h is the channel gain. This is a classic binary signal detection problem in which the CR must decide between two hypotheses, H0 and H1. H0 corresponds to the absence of primary signal in the scanned frequency band while H1 indicates that the spectrum is occupied. It is important to point out here that under H1, the spectrum may be occupied by an incumbent or a secondary user. Hence in Energy Detection it is not only required to detect but also to differentiate between the primary and secondary user signal.

A. Performance Parameters

Conventionally, the performance of detection algorithm is gagged with its *sensitivity* and *specificity* which are measured by probability of detection P_d, probability of false alarm P_f

and probability of missed detection P_m. P_d is the ability of correctly detecting the PU signal present in the scanned frequency band. In terms of hypothesis, it is given as
$P_d = P_r$ (Signal is detected | H_1)

P_f is the probability that the detection algorithm falsely decides that PU is present in the scanned frequency band while in reality it is absent, and it is written as

$P_f = P_r$ (Signal is detected | H_0)

Thus, we target at maximizing P_d while minimizing P_f. Another important parameter of interest is the probability of missed detection P_m which is the complement of P_d. P_m indicates the likelihood of not detecting the primary transmission when PU is active in the band of interest and can be formulated as

$P_m = 1 - P_d = P_r$ (Signal is not detected | H_1)

Total probability of making a wrong decision on spectrum occupancy is given by the weighted sum of P_f and P_m. Hence the key challenge is to keep both P_f and P_m under certain limit as high P_f corresponds to poor spectrum utilization/exploitation by CR and high P_m may result in increased interference at primary user if the missed signal belongs to the incumbent.

B. Threshold Detection

Setting the right threshold is of critical importance. The key problem in this regard is illustrated in fig.1, which shows probability density functions of received signal with active PU. If Γ represents the test statistics in the form of energy content of the received signal. Energy detection differentiates between the two hypotheses H_0 and H_1 by comparing Γ with threshold voltage Vt as

$\Gamma \geq Vt \rightarrow H_1$

$\Gamma < Vt \rightarrow H_0$

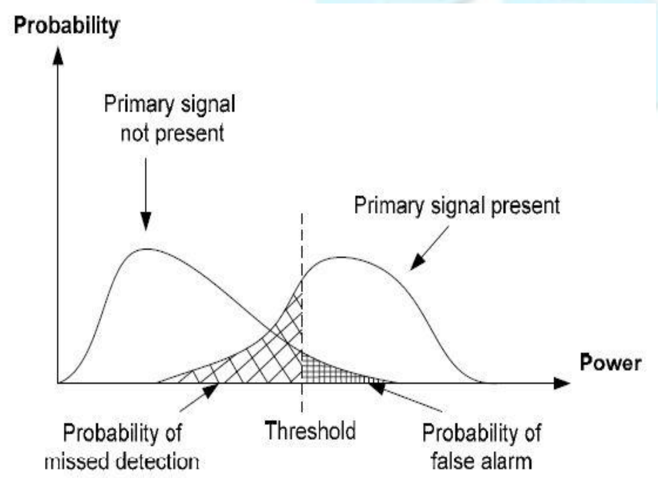

Fig (1) : Threshold setting in ED

Hence if the selected threshold is too low, the false alarm probability ($P_f = P_r$ ($\Gamma \geq V_t / H_1$) is increased which may result in interference with an active PU. Hence, a careful tradeoff is considered while setting the threshold for ED.

C. Study of Energy Detection Algorithm

The process of energy detection can be briefly explained as follows:

a) The Frequency range over which the secondary user is to transmit are decided.
b) The spectrum is scanned to find any holes in the given range
c) Energy detection is done at every frequency in the range by using a Periodogram.
d) Decision metric is calculated from the received signal.
e) The decision matric is compared with a calculated threshold based on the probabilities of detection and false alarm, to come to a decision whether the PU is present or not.

The decision of the energy detector is based on the statistical inference of a hypothesis regarding a signal's presence. The below equation represents the hypotheses described above. The received signal – 'RS' can be either only noise w(n) or signal together with noise (s(n) + w(n)).

$$RS(n) = \begin{cases} w(n) \\ s(n) + w(n) \end{cases}$$

After the signal (RS) is received at the secondary user, each secondary user calculates the decision matric (M) based on which the presence of primary user is decided. The equation for finding the decision metric is as given below.

$$M = \sum_{n=0}^{N} |RS(n)|^2$$

'N' is the observation vector.

D. Advantages:

a) Simplicity: Energy detection is a simple and easy-to-implement technique that requires minimal computational resources.
b) Flexibility: Energy detection can be used for detecting a wide range of signals, including both analogy and digital signals.
c) Low complexity: Energy detection has low complexity and can be implemented in real-time with low computational overhead.
d) Wideband detection: Energy detection can be used for wideband detection of signals over a broad range of frequencies.
e) Robustness: Energy detection is robust to variations in modulation schemes and transmission formats, making it suitable for detecting a variety of signals.
f) Universal: Energy detection is a universal detection technique that can be used with any type of signal,

making it a versatile choice for spectrum sensing in cognitive radio networks.

E. Disadvantages:

a) Sensitivity to noise: Energy detection is sensitive to noise, which can lead to high false alarm rates and low detection probabilities.

b) Requires accurate noise estimation: Accurate estimation of noise power is required to perform energy detection. However, this can be challenging in practice, especially in dynamic and noisy environments.

c) Inability to detect signals with low power: Energy detection requires that the power of the received signal be above a certain threshold to be detected. Signals with low power may not be detected by energy detection, which can lead to missed detections.

d) Limited spectral resolution: Energy detection cannot distinguish between different types of signals within the same frequency band. This can lead to interference with primary users or other secondary users.

5. Cooperative Spectrum Sensing

Given a single frequency band, the first challenge for CR is to reliably detect the existence of primary user to minimize the interference to existing communications. However, the hidden terminal problem occurs when cognitive user is shadowed, in severe multipath fading or inside buildings with high penetration loss while primary user is operating in the vicinity. Due to the hidden terminal problem, the sensing performance for one cognitive user will be degraded. To prevent the hidden terminal problem, the CR network could fuse the sensing results of multiple cognitive users and exploit spatial diversity among distributed cognitive users to enhance the sensing reliability.

Cooperative sensing is a solution to enhance the detection performance, in which secondary users collaborate with each other to sense the spectrum to find the spectrum holes and it helps in solving hidden terminal problems.

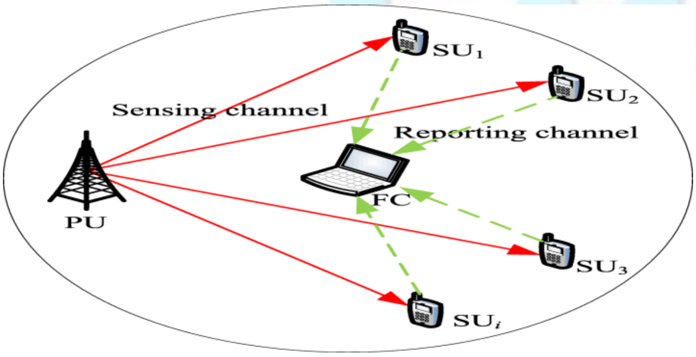

Fig (2) System Model of Cooperative Spectrum Sensing

A. Basic Elements of CSS and Cognitive Radio Network

a) *Spectrum Sensing*: Spectrum sensing is a critical function of cognitive radio to avoid the harmful interference with licensed users and identify the spectrum holes for improving the spectrum's utilization.

b) *Spectrum holes:* These are the licensed frequency bands that are not being used for some time in a specific area.

c) *Primary User:* They are the users who have license to operate in a certain frequency band. Their access to the network is controlled by its base station and it should not be affected by operations of any other unauthorized user.

d) *Secondary User*: These users are also known as cognitive radio users. They do not have spectrum license. Hence, the spectrum access is allowed only in an opportunistic manner. Capabilities of the cognitive radio user include spectrum sensing, spectrum decision, spectrum handoff etc. The secondary user is assumed to have capabilities to communicate with not only the base-station but also other cognitive radio users.

e) *Fusion Centre*: This is the secondary user node which analyses and process the collected local detection data or sensing result according to a specified data fusion rule and determine the final decision on the current channel condition according to the fusion results.

f) *Cognitive Radio Network Access*: Secondary users can access their own cognitive radio base-station both in licensed and unlicensed spectrum bands. Since all interactions occur inside the cognitive radio network, their medium access scheme is independent of that of primary network.

g) *Primary Network Access:* The secondary user can access the primary base-station through the licensed band, if the primary network is allowed. Unlike other access types, secondary users should support the medium access technology of primary network. Furthermore, primary base-station should support cognitive radio capabilities.

B. Classification of Cooperative Spectrum Sensing

Cooperative sensing can be implemented in two fashions: centralized or distributed. These two fashions will be explained in the following sections.

a) Centralized Sensing

In centralized sensing, a fusion centre collects sensing information from cognitive users. The fusion centre identifies the available spectrum and broadcasts this information to other cognitive users or directly controls cognitive user traffic. According to whether cognitive users exchange sensing information themselves, the centralized sensing fashion can also be divided to two categories.

Partially Cooperative Network

Each of CR users detects the channel independently and directly transmits its sensing information to the fusion centre.

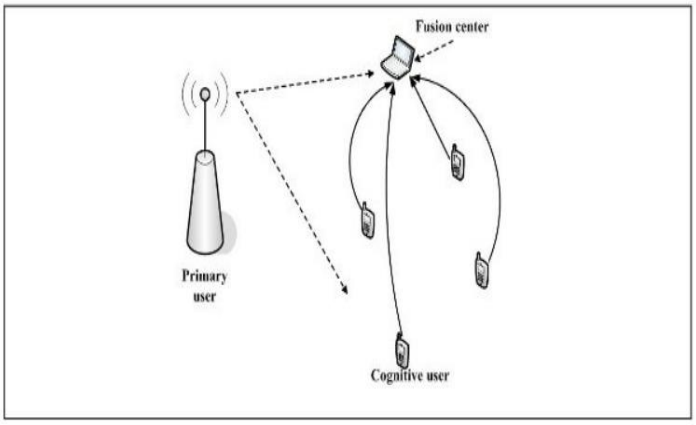

Fig 2.2.1.A Partially Cooperative Network

Totally Cooperative Network

Cognitive users cooperatively transmit each other's sensing information, and then send sensing information to the fusion centre.

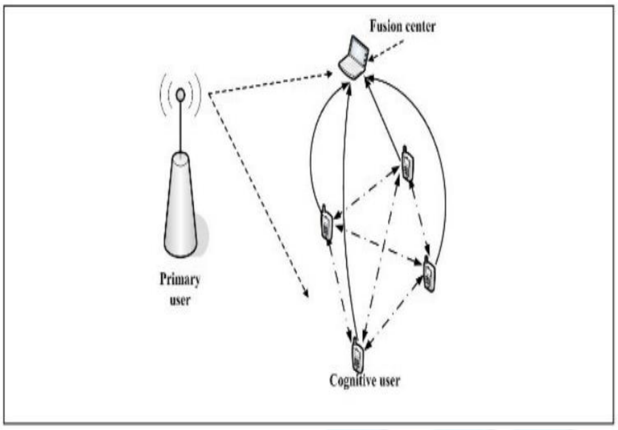

Fig Totally Cooperative Network

b) Distributed Sensing

In the case of distributed sensing, cognitive users share information among each other, but they make their own decisions as to which part of the spectrum they can use. Distributed sensing is more advantageous in the sense that there is no need for a backbone infrastructure.

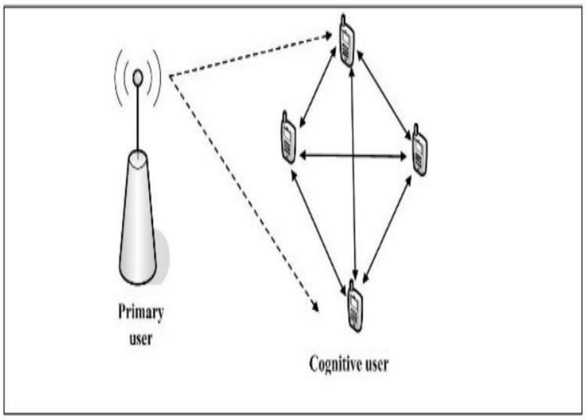

Fig Distributed Sensing

6. Results

A. Periodograms for Secondary Users

When the spectral environment is analysed in frequency domain and power spectral density (PSD) of observed signal is estimated, this approach is termed as Periodogram.

Fig 4.2 represents the periodograms of the ten secondary users.

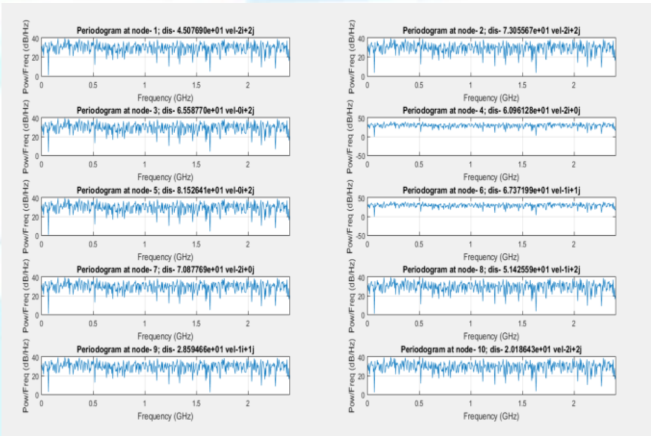

Fig 4.2 Periodogram for secondary users

B. Randomly generated position for nodes

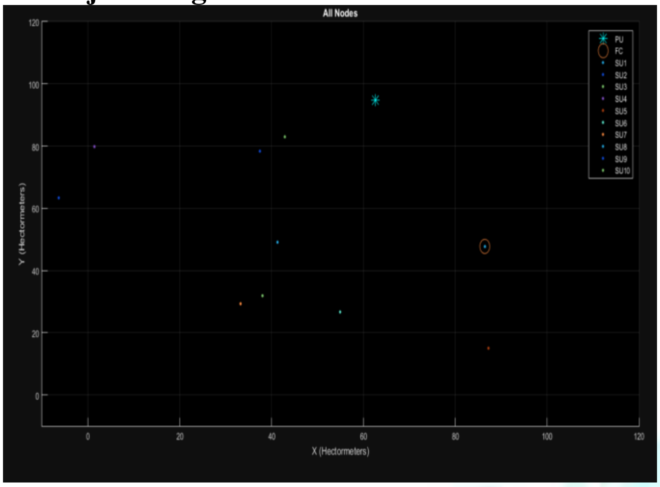

Fig 4.3 Randomly generated position for nodes

C. Original Signal

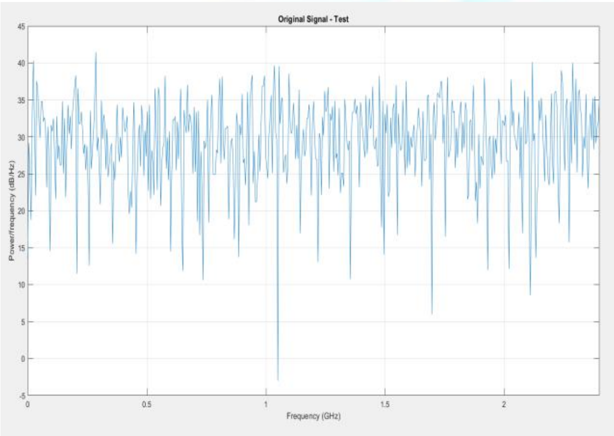

Fig Original Signal

7. Conclusion

In this paper, we discussed the use of CSS in 5G cognitive radio networks with centralized sensing and energy detection. CSS is a promising technique for improving the reliability and robustness of spectrum sensing in CR networks. CSS with energy detection can be implemented using low-cost hardware and can improve the spectral efficiency of CR networks by enabling the identification of unused spectrum. Overall, CSS with energy detection is a promising approach for spectrum sensing in 5G cognitive radio networks, and further research is needed to address the challenges and limitations of this approach.

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