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Comparative Study of Spectrum Sensing Techniques for Cognitive Radio Systems in Noisy Environments

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Abstract—Within the realm of cognitive radio systems, spectrum sensing is an essential component that enables dynamic access to underused spectrum bands while simultaneously coexisting with core users. Due to the existence of a wide variety of interference sources and noise types, however, the implementation of spectrum sensing techniques in noisy environments presents a considerable difficulty. Even when there is noise present, spectrum sensing may be carried out in an efficient manner according to the innovative hybrid technique that is shown in this paper. A variety of values of signal sample sizes and noise uncertainties are taken into consideration in the analysis of the study. Energy Detection (ED), Covariance Absolute Value (CAV), and Joint Estimation mechanism are the three mechanisms that are subjected to the comparative examination. When compared to the conventional methods, the findings demonstrate that the proposed work is superior.

Keywords- Cognitive Radio, Optimization, Energy Detection, Noise, signals.

I. INTRODUCTION

In order to solve the problem of spectrum scarcity, cognitive radio has emerged as a new paradigm that allows for the coexistence of primary users and the dynamic and opportunistic use of underutilized spectrum bands. Cognitive radio systems rely heavily on spectrum sensing, which comprises finding and making use of white spaces in the spectrum. However, a great deal of difficulty arises from the existence of different kinds of interference when attempting to use spectrum sensing methods in noisy situations. Cognitive radio systems rely on spectrum sensing to get access to unlicensed spectrum bands and take advantage of them as they become available, all while avoiding interference with licensed users. Cognitive radios can basically sense when main users are around, find possibilities in the spectrum, and adjust their broadcast settings based on that. However, environmental noise and interference have a significant impact on spectrum sensing's effectiveness. A wide variety of interference sources, including thermal noise, neighboring channel interference, multipath fading, co-channel interference, and man-made interference, are present in noisy surroundings. The difficulty of spectrum sensing is increased by these many interference sources, which calls for strong approaches that can isolate main signals from background noise.

Finding an optimal balance between computing complexity and detection efficiency is a key difficulty in cognitive radio systems' spectrum sensing in noisy situations. In noisy situations, the computational complexity and durability of conventional spectrum sensing approaches including energy detection, matching filter detection, cyclostationary feature identification, and covariance-based detection change. Even though energy detection is well-known for its simplicity and broad sensing applications, it may be influenced by noise uncertainty, which increases the likelihood of false alarms and misdetection in noisy settings. The cyclostationary qualities of main signals may be used by cyclostationary feature detection to improve detection performance, although also increases computational complexity.

Cognitive radio systems have been under fire in recent years due to the prevalence of noise; however, new spectrum sensing methods that use machine learning and signal processing algorithms have the ability to significantly reduce this impact. Methods based on machine learning, such as neural networks, deep learning, and support vector machines, use data-driven models to decipher intricate patterns in spectra with a lot of noise. Adaptively improving detection accuracy while reducing the impact of noise-induced uncertainty is possible using machine learning-based spectrum sensing methods by utilizing historical data and training algorithms on varied noise circumstances.

In addition, new paradigms for collaborative spectrum sensing have shown promise for making spectrum sensing more reliable and resilient in noisy settings. When many cognitive radios work together, they can assess the spectrum, communicate their findings, and make better judgments about how to use it. This is called collaborative sensing. Collaborative spectrum sensing approaches improve cognitive radio systems' detection effectiveness in noisy situations by combining data from several sensing nodes, which reduces the impact of localized interference and noise. In addition, cognitive radios may mitigate interference and noise by utilizing cooperative diversity techniques like relay-assisted sensing and distributed antenna systems to take advantage of spatial variety and cooperative gain.

Spectrum sensing methods for cognitive radio systems have come a long way, yet there are still many unanswered questions and obstacles to investigation. A crucial area of study that has to be addressed is the development of sensing algorithms that can withstand and adapt to many types of noise. Wireless communications, signal processing, machine learning, and regulatory frameworks are all areas that need to be thoroughly investigated in order to integrate spectrum sensing with interference control tactics, spectrum access regulations, and spectrum sharing mechanisms. Further research is needed to address the practical issues of validating and standardizing spectrum sensing systems in real-world noisy situations.

II. REVIEW OF LITERATURE

Mashta, Faten & Altabban, Wissam (2019) Cognitive radio addresses the issue of limited availability of radio spectrum. It allows a secondary user to take use of the spectrum assigned to a major user. The primary purpose of cognitive radio is to do spectrum sensing, which has evolved in recent decades to identify opportunistic spectrum gaps. Several spectrum sensing approaches have been proposed in the literature. The efficacy of these strategies may vary in many scenarios, and may be characterized by metrics such as detection probability, false alarm probability, and sensing duration. It is crucial to evaluate and identify the most optimal strategy for a certain case. This work presents a categorization of the primary methods for single user spectrum sensing based on their synchronization requirement. These methods may be divided into two basic categories: coherent detection and non-coherent detection. Coherent detection requires either partial or complete previous knowledge of the primary user signal in order to detect it, whereas non-coherent detection does not require any prior knowledge of the primary user signal for detection. Furthermore, we emphasize the benefits and drawbacks of narrowband and wideband spectrum sensing methods, as well as the difficulties associated with their execution. Moreover, we provide the notion and fundamentals of cooperative sensing and interference-based sensing. This study aims to familiarize the designer with several strategies employed to accomplish spectrum sensing.

Pandit, Shweta & Singh, Ghanshyam (2017) As a result of the proliferation of various wireless devices and technologies, significant growth in the number of wireless users, emergence of new applications, and persistent need for faster data transmission, the radio frequency (RF) spectrum is experiencing more congested conditions. This advancement necessitates the use of systems and devices that possess knowledge about the radio frequency environment in which they operate. This knowledge enables them to enable adaptable, effective, and dependable usage of the existing spectrum resources. Hence, spectrum sensing is increasingly crucial for contemporary and upcoming wireless communication systems. Its purpose is to detect unused spectrum and analyze interference, aiming to provide dependable and efficient functioning. Cognitive radio refers to an advanced radio system that possesses intelligence and awareness of its surrounding environment. It is capable of acquiring knowledge and adjusting its behavior and operation to effectively align with its surroundings and meet the user's requirements. Spectrum sensing is an essential prerequisite and one of the most formidable challenges for the cognitive radio system. This chapter provides a thorough examination of the spectrum sensing techniques used in the physical layer of cognitive radios. The primary obstacles in spectrum sensing are delineated and several methods for enhancing spectrum sensing performance are examined. In addition, a hybrid model is provided for non-cooperative spectrum sensing. This model incorporates the correct channelization of the three strategies and includes a thorough explanation on the topic. This method facilitates the identification of unused frequency bands in an opportunistic manner, leading to improved usage of the spectrum in situations when cooperative sensing is not possible, ultimately resulting in higher efficiency of the spectrum. Additionally, we investigate the process of sensing within a collaborative setting. The suggested strategy facilitates the opportunistic detection of idle spectrum bands, which are the underused sub-bands of the radio spectrum. This method achieves higher spectrum utilization compared to non-cooperative sensing, resulting in increased overall spectrum efficiency.

Muchandi, Niranjan & Khanai, Rajashri (2016) Cognitive Radio (CR) is a technology with great potential to enhance the efficiency of spectrum usage. The utilization of cognitive radio (CR) enables more efficient utilization of the radio spectrum in response to the growing need for wireless communication. CR is an intelligent network that adjusts to variations in the spectrum environment. Spectrum sensing is the primary focus of cognitive radio. This is a really complex problem in cognitive radio systems. This study presents a comprehensive analysis of spectrum sensing approaches for cognitive radio. The paper provides a comprehensive assessment of several sensing schemes used in cognitive radio and discusses the accompanying problems. The research elucidates the cooperation and signal processing sensing strategies and their many manifestations.

Chatterjee, Subhajit et al., (2015) Cognitive radio (CR) relies on spectrum sensing. The most important criteria for choosing the right spectrum sensing method are inference speed and accuracy. Cognitive radio relies on spectrum sensing, in which the SU checks for the existence of PU signals by analyzing the available radio waves. During the transmission phase, non-stationary PU has been the primary focus of previous research. There is an immediate need to improve spectrum use efficiency due to the exponential growth of wireless users and the shift from voice-oriented to multimedia applications. Spectrum sensing and various spectrum sensing approaches are the main topics of this study, which aims to address many elements and concerns related to cognitive radio.

E., Ireyuwa et al., (2015) One crucial component of cognitive radio networks is spectrum sensing. One of the primary obstacles that cognitive radio faces is spectrum sensing. From a cognitive radio vantage point, this article surveys spectrum sensing strategies. We take a look back at the difficulties of spectrum sensing. We look at two different sensing schemes: eigenvalue-based sensing and cooperative sensing. The many benefits and drawbacks are emphasized. This research lends credence to the idea that cognitive radio systems that operate on wideband might benefit from using cooperative spectrum sensing.

Matin, Mohammad (2014) In order to share the spectrum band with primary users (PUs), Cognitive Radio (CR) users must periodically detect the channel or surroundings. Once the spectrum becomes available, CR users can begin transmitting through it. If they detect a PU attempting to utilize the band, they must quickly exit the spectrum, hence it is necessary for them to keep detecting even when broadcasting. One of the fundamental roles of cognitive radio is to detect PUs before transmission; a greater detection probability means better safety for the primary users. Because there is a tradeoff between the false alarm probability (Pfa) and the probability of detection (Pd), it is not feasible to achieve a high detection probability (or a low miss detection probability) and a low false alarm probability at the same time. The author has given a thorough analysis of several sensing methods and weighed their pros and cons in this work. Additionally, the goal of this paper is to provide readers with a comprehensive overview of sensing approaches in CR as well as the latest research developments in this field.

Jaiswal, Manish et al., (2013) The natural frequency spectrum is a precious resource that, if used wisely, will meet the demands of the computer world of the future. However, the current system, which allocates spectrum according to the fixed spectrum access (FSA) policy, does not allow for its efficient usage. It causes the spectrum to be wasted, according to several surveys. To make the most of the available spectrum, new approaches are required. One way to make use of the spectrum that is accessible is through the Dynamic Spectrum Access (DSA) policy. Because it allows for the opportunistic use of frequency channels that are not widely occupied by licensed users, cognitive radio presents itself as an attractive option for a given goal. The research on several cognitive radio network spectrum sensing methods is detailed in this article. Cognitive radio, in reality, is a method of wireless communication in which the radio transceiver autonomously determines which spectrums are available and which ones are not. Afterwards, it navigates around the crowded one and takes up residence in the empty one. Cognitive radios advocate for free allocation of the radio spectrum, which is different from the old command and control methods. Cognitive Radio Networks, or "infrastructure-less" collaborative network clusters, are made possible by this. Nevertheless, in order to identify unlicensed spectrum, spectrum sensing methods are required. Various spectrum sensing approaches are examined in this work, along with their advantages and disadvantages.

Üstok, Fatih. (2010) This study aims to boost spectrum efficiency by focusing on cognitive radio's spectrum sensing, a newly established technology. There is an immediate need to improve spectrum use efficiency due to the exponential growth of wireless users and the shift from voice-oriented to multimedia applications. Because of the demands of modern wireless technology, dynamic spectrum utilization is essential for wireless networks, as static distribution of the frequency spectrum is insufficient. Because cognitive radios can learn their surroundings and fine-tune their settings, they are a strong contender for use in these kinds of systems. In order to prevent secondary users from interfering with primary users, cognitive radios can sense the spectrum and identify empty frequency bands. When primary users aren't using those bands, secondary users can be assigned to them. For cognitive radio-based systems, many spectrum sensing methods have been suggested

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in the literature. This thesis takes a close look into cognitive radios that use and don't use multiple antennas, analyzing their energy detection and cyclostationary feature detection-based spectrum sensing systems. It then compares their performance in wireless communication channels.

III. RESEARCH METHODOLOGY

This research is evaluated over a range of signal sample sizes and noise uncertainty levels. We employ the Genetic Algorithm and Particle Swarm Optimization to achieve hybridization. Results obtained from testing the suggested method in the MATLAB program show that it significantly outperforms the more conventional methods.

Here is a simplified explanation of the proposed system's methodology:

1. The initial stage in putting the suggested mechanism into action is the deployment of the network.
2. After that, in order to set up the communication and message transmission, you must identify the main and secondary users.
3. In order to apply the PSO optimization, it is necessary to initialize the population once the users have been defined. At random, the population is created.
   (To handle issues where the best answer may be represented as a point or surface in n-dimensional space, a global optimization approach called Particle Swarm Optimization (PSO) can be used.)
4. Step four involves updating the fitness based on a randomly generated population.
5. The Genetic Algorithm (GA), a metaheuristic that draws inspiration from natural selection and is part of the broader family of evolutionary algorithms, will be used next. Here, the formation of the optimized objective function is checked first. Proceed to step 6 if it has taken shape; otherwise, carry out the following procedures:
   a. Initialize the population of chromosomes randomly.
      (The genetic algorithms "chromosomes" are the parameters that specify the problem's intended solution.)
   b. Perform crossover and roulette selection.
   (Crossover is an operator that may be used to generate new solutions from several existing ones, and roulette selection is essentially a fitness function that can be used to assign fitness to different candidate solutions or chromosomes.)
   c. Proceed to step 6 if the optimum fitness values have been reached.
   d. If the optimized fitness has not been attained, repeat steps 1-6 until it is.
6. Check for convergence. Proceed to step 7 if it is achieved; otherwise, return to step 4.
7. Optimization of sensing parameters is done.
8. Carry out simulations in order to examine performance matrices as ROC, SNR, Missed Detection, Probability of detection, and MSE.

IV. DATA ANALYSIS AND INTERPRETATION

In order to effectively suspect the spectrum from signals, even when there is noise present, this study seeks to examine the current spectrum sensing methods and simultaneously develops a hybrid optimal methodology.

Energy Detection, Covariance Absolute Value, Joint estimate, and the proposed technique are compared in terms of detection performance at M=10 and M=100, respectively, in Table 1. It demonstrates that the detection probability is improved with more samples. When compared to more conventional methods, the one put out here works better.

Table 1 Comparison of Performance at M=10 and M=100

SNR (db)	**Pd of Energy Detection**		**Pd of Covariance Absolute Value**		**Pd of Joint Estimation**		**Pd of Proposed Method**	
	M=10	**M=100**	**M=10**	**M=100**	**M=10**	**M=100**	**M=10**	**M=100**
-20	0.1	0.4	0.1	0.46	0.2	0.6	0.51	0.69
-12	0.26	0.6	0.2	0.84	0.4	0.97	0.9	1
-10	0.41	0.5	0.6	0.8	0.5	0.97	0.8	1

The comparison of detection performance based on different noise uncertainties (0, 1, and 5 dB) is shown in Table 2. With minor changes in Detection Probabilities of around 0.01 and 0.02 at 0, 1, and 5 dB, the suggested methodology, Joint Estimation, and CAV method, are less vulnerable to noise uncertainties, as shown in the table. However, the ED approach is more vulnerable to noise uncertainties, as evidenced by a fluctuation of around 0.2564 in Detection Probability. The suggested method has a greater Detection Probability when compared with all of these values at 0, 1, and 5 dB.

Table 2 Comparison of Performance on the basis of the different noise uncertainties

Techniques	**0dB**	**1dB**	**5dB**
Proposed Technique	0.46	0.45	0.49
Joint Estimation Mechanism	0.19	0.17	0.2
CAV mechanism	0.12	0.10	0.15
ED Mechanism	0.26	0.0032	0.0032

V. CONCLUSION

In order to aid cognitive radios, this research creates new and intelligent methods of spectrum detection. Cognitive radio relies heavily on spectrum sensing. There have been a lot of methods created to perceive it efficiently; however, they all fall short when signals are mixed with noise that has very small fluctuations. As a result, we examine the suggested spectrum sensing method across different signal noise uncertainties. With respect to Detection Probability, Signal-to-Noise Ratio, and Mean Squared Error, the results section demonstrates the superiority of the suggested approach over conventional methods. The suggested work's performance is validated using the information from the produced tables. Although they lay the groundwork for spectrum sensing, traditional methods like energy detection and cyclo-stationary feature recognition aren't very resilient and computationally complex when used in noisy conditions. New collaborative sensing techniques and machine learning-based methods, however, provide encouraging prospects for reducing noise's negative impacts and enhancing detection performance.

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