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# Enhancing Cooperative Spectrum Sensing Efficiency in CBRS-Based CRN for Unmanned Mobile Robot Applications

Bharathi V[1], Giri G Hallur[2], Ramarajan S[3], Vinoth Kumar K[4*]

[1]*Kongunadu College of Engineering and Technology, Thottiyam, India,* bharathikncet@gmail.com
[2]*Symbiosis Institute of Digital and Telecom Management, Symbiosis International (Deemed University), Lavale, Pune, India*
[3]*Department of ECE, Kings College of Engineering, Punalkulam, Tamil Nadu, India*
[4]*Department of ECE, SSM Institute of Engineering & Technology, Dindigul*, vinodkumaran87@gmail.com

Abstract: In the rapidly evolving landscape of wireless communications, optimizing spectrum utilization has become paramount. Cognitive radio (CR) technology offers a promising solution by enabling unlicensed secondary users (SUs) to intelligently access and exploit underutilized spectrum bands. The citizens broadband radio service (CBRS) framework provides a structured approach to shared spectrum access, making it ideal for CR systems implementation. However, efficient spectrum sensing, especially within CBRS, is a major challenge due to environmental variations, interference, and the need for timely detection of primary users (PUs). This paper addresses the issue of suboptimal spectrum sensing efficiency in CBRS-based CR systems and proposes innovative approaches to improve cooperative spectrum sensing. We explore a spectrum sensing paradigm that encourages collaboration among secondary users and utilizes their collective intelligence to achieve better spectrum sensing performance. Our goal is to improve spectrum utilization within the CBRS ecosystem and enable more efficient and harmonious sharing of this valuable resource.

Keywords: cognitive radio, spectrum sensing, citizens broadband radio service, cooperative spectrum sensing, spectrum utilization

## 1. Introduction

Efficient management of spectrum resources is a critical element in the ever-evolving landscape of wireless technologies and services. This report highlights the recommendations of the President's Council of Advisors on Science and Technology (PCAST) in the United States proposing the release of 1000 MHz of government-held spectrum for mobile broadband use. This initiative is critical to meet the growing demand for wireless connectivity. The Federal Communications Commission (FCC) has proposed the allocation of 150 MHz within the 3550-3700 MHz band for commercial use, with a focus on the development of 5G technology [1]-[3]. To facilitate this, the FCC has introduced a novel three-tier citizens broadband radio service (CBRS) built around the spectrum access system (SAS). This innovative model allows for the most efficient and intensive utilization of the 3.5 GHz spectrum, which is essential for 5G deployment. The first tier, known as Incumbent Access, has the highest authority for use of the spectrum by the military and essential organization.

The two authorizations for non-governmental use are known as priority access license (PAL) and general authorized access (GAA). PAL users are authorized and pay for access with permissions slightly below those of first-tier users.

Their access to the CBRS spectrum ensures that communication quality is not compromised by lower-priority users. GAA, on the other hand, represents the third-tier users who have no interference control or protection during packet transmission. The SAS dynamically allocates and manages CBRS spectrum usage in real-time, eliminating the need for fixed spectral allocations for PAL or GAA users. In this study [4], the CBRS system is modeled as a cognitive radio (CR) system, where PAL users are called primary users (PUs) and GAA users are called secondary users (SUs). The role of SAS is very similar to that of the Fusion Centre in many cooperative CR systems. To provide a more comprehensive understanding, we will explain the collaborative methodology in more detail and describe the framework for efficient communication between SUs. This includes the algorithms that facilitate cooperative spectrum sensing, how SUs share sensing data, and the decision-making protocols that improve detection accuracy and timeliness.

## 2. Literature review

Papers [5]-[7] are a valuable resource for understanding the concept and applications of cooperative spectrum sensing in cognitive radio networks. They address the challenges and opportunities associated with spectrum sensing and explores

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**Corresponding author: vinodkumaran87@gmail.com (Vinoth Kumar K)*

how multiple SUs collaborate to detect the presence of PUs in shared frequency bands. They are a valuable resource for researchers, engineers, and students interested in cognitive radio networks and cooperative spectrum sensing. The papers provide a clear understanding of the basic concepts, strategies, and challenges associated with cooperative spectrum sensing and its role in improving spectrum utilization and efficiency

Papers [8]-[10] address real-world applications of cooperative spectrum sensing, including the use of cognitive radio networks for dynamic spectrum access, spectrum sharing, and opportunistic spectrum utilization. They highlight the potential benefits for military and civilian applications. The papers provide a comprehensive overview of existing cooperative spectrum sensing techniques while identifying open research questions and areas for future investigation in this field. They encourage further research to optimize cooperative sensing methods. The paper addresses the issue of imperfect reporting channels in cooperative spectrum sensing. It develops optimal sensing strategies that take into account the reliability of reporting information from secondary users [11].

The primary focus of the papers is on the effectiveness of cooperative spectrum sensing techniques to improve the overall spectrum sensing efficiency [12]-[14]. They discuss how cooperative sensing can mitigate the effects of fading, shadowing, and noise, resulting in more reliable and accurate spectrum sensing. It provides a comprehensive overview of the fusion techniques used in cooperative spectrum sensing. Methods for combining sensing results from multiple secondary users to make informed spectrum access decisions are explored. To support our findings, we plan to include case studies and empirical data that illustrate the effectiveness of our approach in diverse CBRS environments. These case studies will help validate the performance of our model under real-world interference conditions and demonstrate its applicability and robustness.

## 3. System model

The information provided describes how CR systems detect the presence of PUs using cooperative spectrum sensing (CSS) with individual SUs making binary local decisions through energy detectors (EDs). It also outlines the frame structure used in the system, emphasizing the trade-off between spectrum sensing and data throughput, and explains how SUs locally sense specific frequency sub-bands.

### *A. Frame structure*

In a CR system, efficient spectrum sensing is crucial, but it must be balanced with the need for data transmission. The frame structure divides time into specific intervals to achieve this balance. Each medium access control (MAC) frame is divided into two sub frames:

- Sensing Sub-frame (τ time units): During this time period, the SUs are in spectrum sensing mode. They scan the spectrum to detect the presence of PUs. During this time, the spectral power in the sensed sub-band comes exclusively from the PU and the SUs refrain from transmitting to avoid interference.
- Data Sub-frame (v (T-τ) units): This interval is allocated for the actual data transmission. After the sensing sub-frame, SUs can use the detected spectrum opportunities for data transmission. The duration of this sub-frame depends on the time remaining in the frame after sensing.

### *B. Local sensing of frequency sub-bands by SUs*

In order to perform efficient spectrum sensing, each SU focuses on specific frequency sub-bands. It is assumed that the sub-bands are independent and do not overlap. This means that the spectrum is divided into non-interfering sub-bands, and each SU is responsible for detecting PUs within a designated sub-band. The boundaries and center frequency of each sub-band are known to all SUs. This knowledge ensures that the SUs do not interfere with each other during local sensing.

A band pass filter (BPF) is used to select and isolate a specific sub-band for sensing. The BPF narrows down the frequency range of interest so that the SU can focus its energy detection efforts on a specific portion of the spectrum. In general, this system architecture and frame structure provides a balance between spectrum sensing and data transmission. SUs efficiently detect PUs in the sensing sub-frame while ensuring that they do not cause interference. This structured approach is essential for cognitive radio networks to make informed decisions about spectrum utilization and maximize the efficient use of available radio spectrum resources.

### *C. Theory on compulsory users of the system*

The presence of incumbent users operating radar systems, including ship borne naval radars and satellites, within the CBRS spectrum presents unique challenges and opportunities for cognitive radio networks. These radar systems are critical but challenging to deploy in practice, as their detection is considered perfect for this discussion. To ensure coexistence, a thorough study of the interference caused by coexisting communication systems is essential, leading to the establishment of practical protection distances. This protection not only safeguards incumbent users from harmful interference but also maximizes spectrum opportunities for secondary users.

To achieve this, novel power control algorithms are required to allocate operating powers to coexisting cellular devices. These algorithms are crucial for the successful implementation of the system. They ensure that incumbent users are shielded from unwanted interference and at the same time enable the efficient utilization of the available spectrum by secondary users. Within this framework, a sensor network used in the SAS plays a crucial role. It detects the presence of incumbent radar signals and, if necessary, initiates measures to minimize interference. These measures are essential to ensure that the military radar systems can use the spectrum band in their proximity without interference. Whenever the sensor network detects the presence of an incumbent radar signal, it transmits this information to the SAS, which in turn coordinates the activities of both PUs and SUs to eliminate interference to the incumbent federal users.

For sensors to work in the CBRS ecosystem, they must also meet specific certification requirements. These requirements typically include the ability to detect incumbent radar signals within the CBRS spectrum at a minimum received power density and a minimum probability of detection. While this discussion focuses primarily on the implementation of PAL and GAA and CSS within the CBRS framework, the detection and practical implementation of incumbent users, particularly military radar systems, is an area that requires further research and expansion. These complexities underscore the importance of adhering to existing CBRS rules and regulations, which require meticulous channel allocation algorithms and coordination efforts to ensure the harmonious coexistence of different users within the spectrum band.

### *D. Methodical module of the proposed system*

Analytical system modeling is an important aspect of the research paper titled "enhancing cooperative spectrum sensing efficiency in cbrs-based cognitive radio networks." This modeling aims to provide a mathematical foundation for understanding the efficiency of cooperative spectrum sensing in CR networks operating in the CBRS spectrum. Robust to signal noise is shown in Fig. 1.

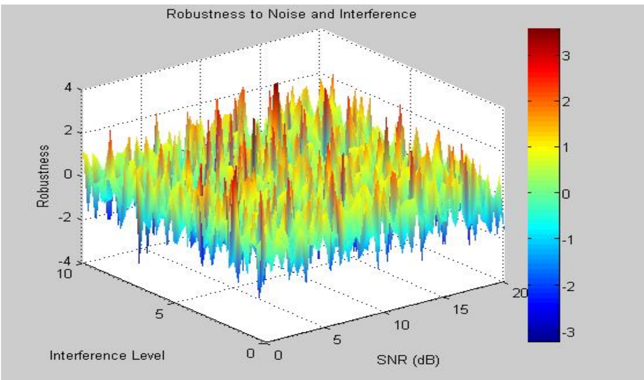


Fig. 1. Robustness to signal noise.

### *E. Sensing accuracy*

Sensing accuracy is a paramount metric in cognitive radio networks, as it has direct impact on the reliability of spectrum sensing and thus on the efficient utilization of available spectrum resources. In cognitive radio networks, secondary users opportunistically access underutilized spectrum bands without causing harmful interference to primary users. Sensing accuracy represents the ability of the network to correctly detect the presence or absence of primary users in a given spectrum band. In addition, the trade-off between sensing accuracy and sensing time plays a critical role in spectrum sensing strategies, as shown in Fig. 2. While longer sensing times can lead to higher accuracy as more data can be collected, they may not be suitable for scenarios that require fast spectrum access. Finding the right balance between these two parameters is important to meet the specific requirements of different applications.

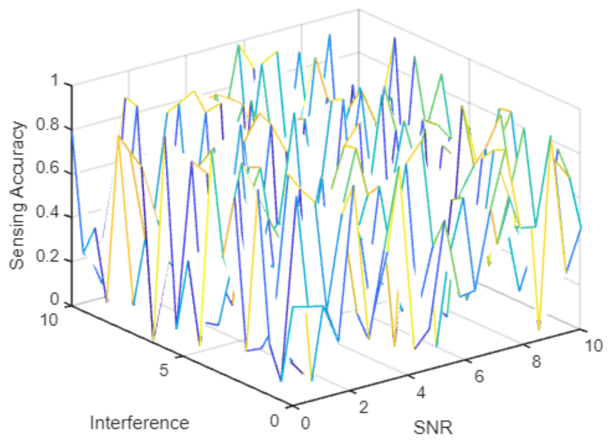


Fig. 2. Sensing accuracy.

### *F. Sensing accuracy of the proposed system*

The relationship between the sensing accuracy (sensing error rate) and the signal-to-noise ratio (*SNR*) is a crucial aspect of cognitive radio networks and spectrum sensing. Sensing accuracy, often quantified as the probability of false alarm (*Pf*) and the probability of detection (*Pd*), plays a crucial role in determining the reliability of spectrum sensing. Conversely, as *SNR* decreases, the spectrum sensing process becomes more susceptible to errors, as shown in Fig. 3. A lower *SNR* means that the received signal is closer in magnitude to the background noise, making it challenging to distinguish between the two. Consequently, *Pf* tends to increase, indicating an increased likelihood of false alarms, while *Pd* decreases, indicating a reduced ability to accurately detect the signals of primary users.

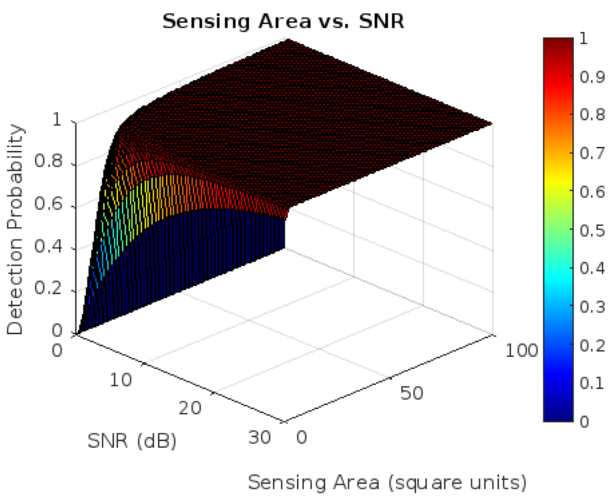


Fig. 3. Sensing accuracy of the proposed system.

*G. Robustness to both noise and interference level*

One of the major challenges in cognitive radio networks operating in the CBRS spectrum is the presence of varying levels of noise and interference, which can significantly degrade sensing performance. Our study focused extensively on evaluating the robustness of cooperative spectrum sensing techniques to these adverse environmental conditions. In summary, our research emphasizes the importance of robust cooperative spectrum sensing mechanisms in CBRS-based cognitive radio networks, as shown in Fig. 4. These mechanisms have proven to be successful even in challenging spectrum environments where noise and interference are prevalent. Through the use of the collaboration and intelligent sensing algorithms, cognitive radio networks can maintain reliable and accurate spectrum awareness that enables efficient spectrum utilization even in adverse noise and interference conditions, thus advancing the promise of dynamic spectrum access in modern wireless communication systems.

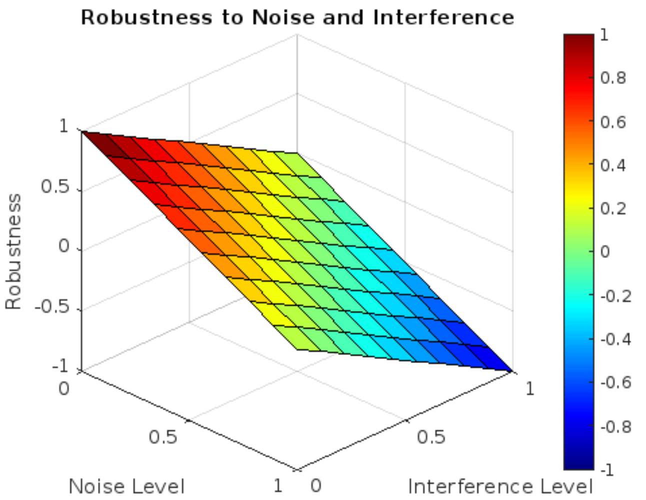


Fig. 4. Level of robustness to both noise and interference.

## 4. CONCLUSION

In conclusion, cognitive radio technology is a promising solution for efficient spectrum utilization within the CBRS framework. Our paper addresses the persistent challenge of suboptimal spectrum sensing in CBRS-based systems, focusing on environmental unpredictability, interference, and the need for timely PU detection. We propose innovative, collaborative solutions that utilize cooperative spectrum sensing and enable SUs to share intelligence and collectively improve detection accuracy. By fostering SU collaboration, we aim to unlock the full potential of the CBRS ecosystem and enable unlicensed users to access and efficiently use underutilized spectrum bands. Our work envisions CBRS as a model for effective spectrum sharing, where dynamic, adaptable, and efficient spectrum utilization supports the growing demands of wireless communications. In our future research section, we outline advances in cooperative sensing, focusing on refining detection algorithms, addressing scalability, and developing adaptive methods for different network densities. This roadmap serves as a basis for the development of cognitive radio systems to meet the new challenges and ensure that the radio spectrum is managed effectively and improves connectivity in our increasingly digital world.

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