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Research Article

Enhancing Hybrid Spectrum Access in CR-IoT Networks: Reducing Sensing Time in Low SNR Environments

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ABSTRACT

The current utilization of the licensed spectrum band is not optimal. the abundance of Internet of Things (IoT) gadgets could lead to congestion in the unlicensed spectrum band. A potential solution is to integrate cognitive radios into IoT devices, specifically by developing CR-IoT (cognitive-radio-enabled IoT) devices that leverage the hybrid spectrum access (HSA) technique to access the licensed spectrum band and employ energy detectors for spectrum sensing. While HSA can enable high data throughput for CR-IoT networks, environments with low signal-to-noise ratio (SNR) may experience reduced performance. Particularly, in low SNR environments with SNR values ranging from -20dB to -24dB, the high level of noise uncertainty can cause the energy detector to spend more time sensing, which results in a significant reduction in transmission time and overall throughput. In this study, a novel approach is presented to address the challenge of noise uncertainties on the energy detector by implementing an adaptive sensing threshold. The simulation outcomes reveal that the proposed technique can significantly improve the throughput in scenarios characterized by low signal-to-noise ratio (SNR), with a maximum enhancement of up to 28%. This innovative approach can pave the way for more robust and efficient energy detectors in the presence of noise uncertainties.

1. INTRODUCTION

As the world moves towards a fully connected smart future, the growth of IoT devices has increased the need for better RF spectrum management. The unlicensed spectrum band is becoming overcrowded, with IoT devices projected to reach 29 billion by 2030 [1-5]. Meanwhile, the FCC reported that the licensed spectrum bands are underutilized [6-8]. The licensed bands are sometimes idle because primary users only sometimes use them at all times or to their full capacity. IoT devices can use cognitive radios to access these underutilized licensed bands and alleviate the overcrowding in the unlicensed band. Creating CR-IoT devices (IoT devices equipped with cognitive radios) addresses the two spectrum management problems simultaneously.

CR-IoT devices have recently advanced by utilizing the energy detector to detect the spectrum and using the hybrid spectrum access (HSA) technique to access the licensed spectrum band, which blends the underlay and interweave techniques. These CR-IoT devices identify the targeted radio frequency (RF) bands with the energy detector. If the primary user (PU) is absent, meaning that the energy detector's received signal is lower than the preset sensing threshold, the CR-IoT device employs the interweave technique to enter the RF band with the highest allowable power. Conversely, if the PU is detected, i.e., the energy detector's received signal is greater than the specified threshold, the CR-IoT device reduces its transmission power to a level below the noise temperature and obtains access to the spectrum band alongside the PU through the underlay technique. The HSA technique delivers high data throughput for CR-IoT networks, but the low signal-to-noise ratio (SNR) environments can impair this performance.

As illustrated in Figure 1, in the context of CR-IoT devices that rely on an energy detector for spectrum sensing, a frame consists of two distinct and sequential periods, namely the sensing time and the transmission time. These periods are separate and independent, yet integral components of the frame structure. In low SNR environments, the energy detector is affected by noise uncertainties and spends more time sensing, leading to decreased transmission time and throughput. In other words, low SNR conditions can counter the benefit of using the HSA technique, which is designed to provide high data throughput for CR-IoT devices. Furthermore, compared to other spectrum access methods, HSA is computationally more demanding.

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So, it is important to ensure that the benefits of using HSA outweigh the computational cost for the CR-IoT device, even in low SNR environments.

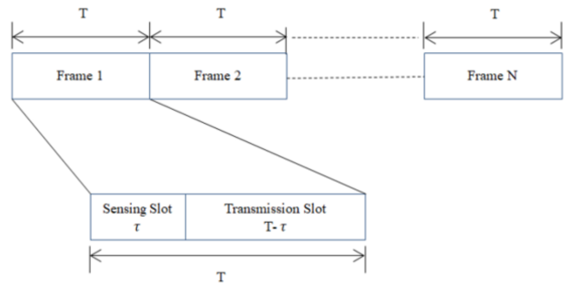

Fig 1. Frame duration for sensing in CR-IoT device

In low SNR environments, the task is to decrease the sensing time of CR-IoT devices while maintaining the precision of the energy detector's sensing outcomes. This paper introduces an adaptive sensing threshold algorithm to address this issue. The proposed algorithm adjusts the energy detector's sensing threshold based on the environment's SNR levels.

The paper's organization is structured as follows: Section I presents an overview of related works and highlights the paper's main contributions. Section II outlines the system model employed in this study. Section III presents and discusses the results obtained from the simulations conducted. Finally, Section IV provides a summary of the paper's findings and conclusions drawn from the study.

2. RELATED WORKS AND MAIN CONTRIBUTION

In recent years, numerous research papers have explored ways to optimize the throughput of CR-IoT networks. Several of these works have been reviewed and analyzed in this section.

In reference [9], a revised frame structure is proposed that addresses the trade-off between sensing duration and system throughput in cognitive radio-based IoT systems. The suggested approach optimizes the frame structure to achieve an appropriate balance between reliable spectrum sensing and effective spectrum utilization, thereby enhancing the overall network throughput. According to this approach, the duration of transmission remains constant, irrespective of the amount of time consumed by the energy detector during sensing. [10], on the other hand, suggests using advanced cognitive radios that can sense and transmit simultaneously. Some researchers, such as those in [11] and [12], rely on machine learning to predict the likelihood of idle licensed bands, thereby reducing the sensing time by only sensing a few channels. However, these solutions have high computational overhead and may be too expensive for battery-constrained IoT devices.

In the research conducted by [13-16], the focus was on improving the sensing performance of the energy detector. [17]'s researchers discovered that in low SNR environments, the energy detector with a dynamic sensing threshold provides better results than one with a fixed threshold. Another study by [18-24] used an adaptive sensing threshold for CR-IoT devices using interweave spectrum access. Their results showed that the dynamic sensing threshold improves the ability of the energy detector to combat noise uncertainties and, therefore, spends less time sensing.

This paper builds on the work of [3] and [23]by proposing a dynamic sensing threshold for the energy detector used by CR-IoT devices that use the hybrid spectrum access (HSA) technique. Unlike [3], which focuses on the interweave spectrum access technique, this paper focuses on the HSA. The HSA offers enhanced QoS (Quality of Service) performance compared to CR-IoT (Cognitive Radio-Internet of Things) networks by enabling uninterrupted transmission in the presence of PU.

To summarize, this paper's primary contributions are:

Investigation of the impact of low SNR environments on the achievable throughput of CR-IoT networks

Proposed an adaptive sensing threshold algorithm to mitigate the dip in throughput caused by low SNR environments in CR-IoT networks using HSA

3. SYSTEM MODEL

The CR-IoT network modelled in this study is comprised of three CR-IoT devices that dynamically access the licensed spectrum. Each CR-IoT device uses an energy detector to sense the targeted RF bands. The energy detector features an adaptive sensing threshold function, which adjusts its threshold level based on the SNR in the RF environment, as shown in Fig. 2. A higher threshold is set in high SNR conditions. In comparison, a lower threshold is set in low SNR conditions. The ED output is an aggregator function and mathematically expressed as in equation 1.

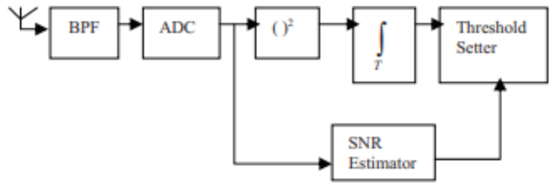

Fig. 2. Energy detector with dynamic sensing threshold

$$T_d = \sum_{n=1}^{N} |y(n)|^2 \quad (1)$$

The test statistic value, T, is compared to the dynamically set threshold value. When the test statistic exceeds the threshold, it signifies that a primary user (PU) is active in the RF channel i.e. ($T > \delta$). Conversely, ($T < \delta$) represents the PU is deemed absent. The status of the sensed RF channel is then passed to the hybrid spectrum access function.

This function determines the appropriate transmission power for the CR-IoT device. If the PU is present, the underlay function is activated, setting the CR-IoT device's transmission power to *low* to enable coexistence with the PU without detection or interruption. If the PU is absent, the interweave function is activated, setting the CR-IoT device's transmission power to *high* to allow full use of the available spectrum. A flowchart of the proposed system model is shown in Fig. 3.

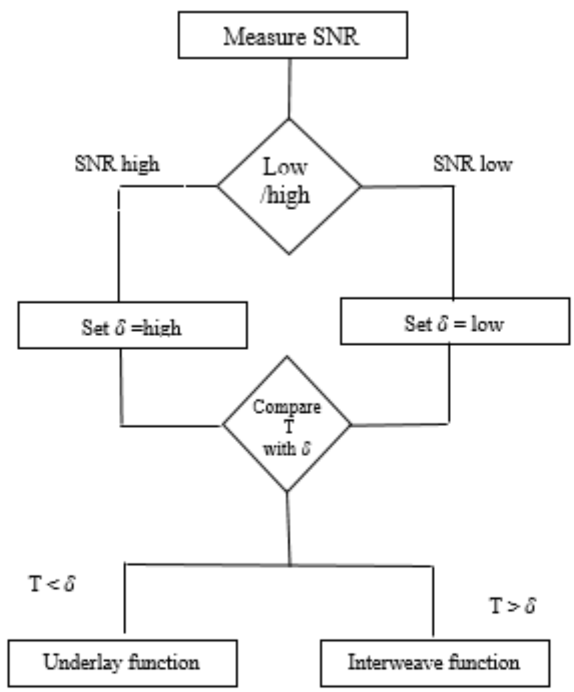

Fig.3. Flow diagram of proposed approach

4. RESULTS AND DISCUSSION

The assessment of the proposed scheme's performance through simulations conducted using MATLAB 2013a, following the guidelines and specifications set forth in the IEEE 802.22 standard. The simulations are done to rigorously evaluate the efficacy of the projected scheme, while also examining its suitability for deployment in real-world cognitive radio-based IoT systems. The proposed system was compared to two other conventional systems. The first conventional system referred to as Conv., did not utilize any sensing threshold adaptation or hybrid spectrum access (HSA). The second conventional system, labeled Scheme 1, employed HSA but did not incorporate the sensing threshold adaptation. Lastly, our proposed system, Scheme 2, incorporated both sensing threshold adaptation and HSA.

Figure 4. illustrates the throughput of the three systems based on sensing time. The duration of the total frame is 100ms. Based on the simulation outcomes, it was observed that the conventional scheme (Conv.) attained a maximum throughput of approximately 1bps/Hz after 60ms of channel sensing. These findings provide valuable insights into the limitations and performance characteristics of the conventional scheme, thereby highlighting the need for more effective and efficient approaches to cognitive radio-based IoT systems. Scheme 1, with only sensing threshold adaptation, can attain a peak throughput of 4.3 bps/Hz after sensing for 15ms. Meanwhile, the proposed scheme 2, incorporating both sensing threshold adaptation and HSA, achieves a maximum throughput of 5.5 bps/Hz with only 5ms of sensing time.

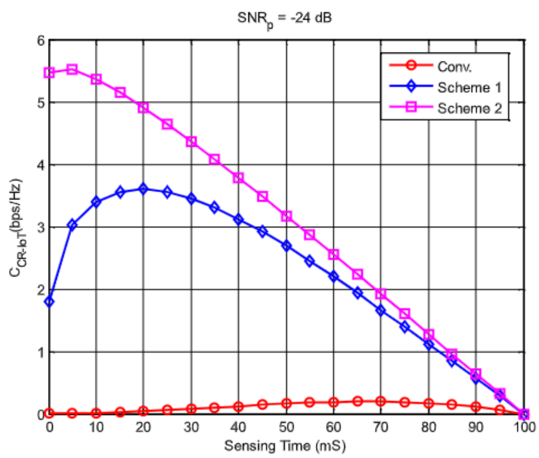

Fig. 4. Achievable throughput as a function of sensing time for CR-IoT System

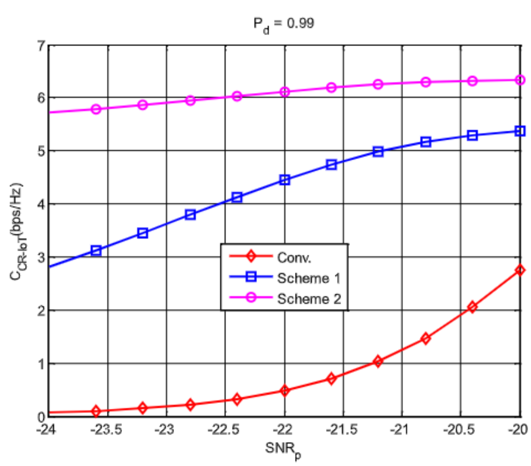

Figure .5. Achievable throughput vs. SNR

Figure 5. shows the relationship between CR-IoT throughput and received SNR. The analysis was conducted in a simulated noisy environment, where the SNR values varied between -24 dB and -20 dB. It was discovered that as the received SNR from the PU improves, the CR-IoT throughput improves due to faster sensing decisions and more time allocated for data transmission. The proposed scheme's ability to adjust its sensing threshold results in the highest possible throughput, which ranges between 5.8 bps/Hz and 6.2 bps/Hz.

5. CONCLUSION

The purpose of this investigation is to identify the ways to improve spectrum efficiency of CR-IoT networks in scenarios in low SNR scenarios. Our proposed solution aims to overcome the drawbacks of the traditional hybrid spectrum access (HSA) method, which can suffer from low SNR, leading to diminished data throughput. By incorporating an adaptive sensing threshold function in the energy detector, the sensing time can be reduced, allowing for sufficient time for data transmission, even in low SNR environments. The proposed approach dynamically adjusts the sensing threshold based on the received SNR, thereby mitigating noise uncertainties, reducing sensing without sacrificing sensing accuracy.

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Conflicts Of Interest

The paper states that the author has no financial or non-financial interests that could be perceived as influencing the research or its interpretation.

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