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Cognitive Radio Networks for Opportunistic Spectrum Use in Internet Delivery

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Abstract

Advancements in wireless technology and the increased demand for high-speed internet access necessitate improved and efficient spectrum utilization. Cognitive Radio Networks (CRNs) enable opportunistic access to and use of previously unexploited frequency bands, alleviating the spectrum access problem. The purpose of this paper is to investigate how CRN uses dynamic spectrum access to improve the performance of internet delivery. Secondary users periodically transmit and receive in the spectrum 'holes' used by primary users. Secondary users enhance spectrum utilization by adding to the overall system capacity. In unserved and underserved rural and remote areas, the densely populated primary users representing the broadband system are overwhelmed. More timely broadband access in rural and remote areas is enabled by CRN's ability to quickly and efficiently detect, learn, and adapt to environmental changes. This paper analyzes the system's architectural framework, the applicable functional elements, and the recognized primary challenges in spectrum utilization. Challenges included are the extent to which the Spectrum can be sensed and the degree to which spectrum policy and operational specification compliance can be achieved. This paper documents the application of hand-optimized and emerging machine learning and artificial intelligence techniques to cognitive control of spectrum access and use in CRNs. CRNs operating in complex multiservice networks are analyzed and

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described in this paper. In closing, the research informs us about the implementation of cognitive radio to address the spectrum access problem and about the technology's versatility in providing efficient and equitable Internet access in heterogeneous environments.

Keywords: Cognitive Radio, Opportunistic Spectrum Access, Dynamic Spectrum Management, Internet Delivery, Spectrum Efficiency, Wireless Communication, Network Intelligence.

1 Introduction

1.1 Brief Overview of Cognitive Radio Networks

Cognitive Radio Networks (CRNs) enable intelligent and flexible use of the radio frequency spectrum in wireless communication systems. Mitola (1999) first proposed the concept of cognitive radios and their ability to reduce communication bottlenecks and increase spectrum efficiency. In the structure of CRNs, the main users are divided into Primary Users (PUs) and Secondary Users (SUs) who are licensed to use a specific band of the Spectrum, and opportunistic users who switch layering without jamming the PUs (Haykin, 2005). These networks are equipped to spectrum-sense, manage, and access spectrum dynamically in areas where the network controls the spectrum. The paradox of the underused Spectrum, in which available bandwidth is unused or underused at different times and different conditions (Akyildiz et al., 2006; Padhye & Shrivastav, 2024), can be solved by SUs.

1.2 Significance of the Opportunistic Spectrum Usage in Internet Delivery

Global demand for consistent, fast Internet is a worldwide concern, especially as technology advances with smartphones, the Internet of Things, and streaming applications. Nonetheless, outdated fixed-bandwidth spectrum policies, especially in densely populated metropolitan areas and rural, underserved areas, continue to blatantly undermine bandwidth optimization (Zhao & Sadler, 2007). CRNs are a remarkable innovation as they provide opportunistic spectrum access (OSA), which allows for the Spectrum to be identified and utilized by secondary users (SU) to transmit data packets over the Internet through unused frequency bands (Rafiei & Bahmani, 2015). This alone offers the possibility of much greater bandwidth, lower delays, and a substantially higher level of service (quality of service) in internet delivery (Yucek & Arslan, 2009). Opportunistic spectrum usage also has the greatest impact on providing internet access to remote areas with limited resources. For example, rural and disaster-affected regions with inadequate infrastructure can leverage some CRN-based technologies designed to support broadband and emergency communication services. Furthermore, CRNs enable spectrum sharing, a fundamental aspect of 5G and beyond-5G ecosystems, with their multi-user service dimension in highly heterogeneous scenarios.

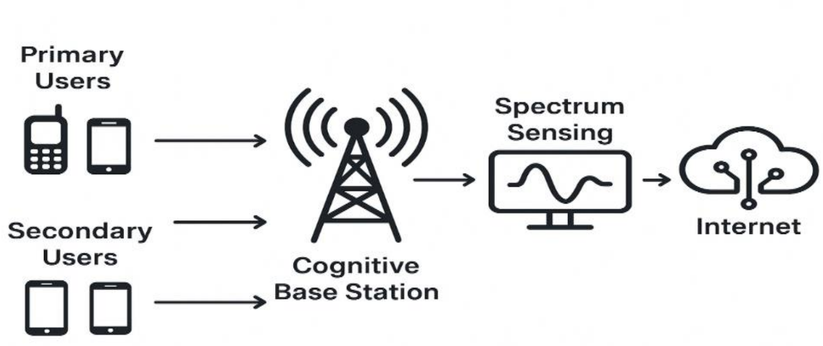

Figure 1: High-level system architecture of a cognitive radio network (ChatGPT, 2025)

The described framework (Figure 1) summarizes a Cognitive Radio Network (CRN) architecture designed to optimize spectrum use and internet service provisioning. The system consists of two primary user types: Primary Users (PUs), who are within the boundaries of a defined geographical region and have licensed access to specific spectrum bands, and Secondary Users (SUs), who opportunistically use unused Spectrum without hindering the PUs. Both user categories exchange information with the CBS, which dynamically allocates Spectrum. The CBS has integrated a Spectrum Sensing Unit, that routinely analyzes a radio band to detect unoccupied frequencies by detecting primary user signals. Secondary-user spectrum-sensing support enables smart communication without compromising service quality. Once the optimal frequency is selected, data for both users are transmitted via the CBS using an internet-delivery mechanism designed to improve connection and bandwidth efficiency (Gunalan et al., 2023). This is particularly advantageous when developing innovative communication systems in scenarios characterized by fragmented or segmented spectrum resources.

1.3 The Research Paper's Objectives

This paper aims to evaluate the role of Cognitive Radio Networks (CRNs) in enhancing internet delivery services by analyzing unimpeded spectrum provision. More precisely, it focuses on improvements to internet delivery services attributable to the CRN's mechanisms for addressing spectrum piracy and access during periods of congestion. This research also delves into artificial intelligence and machine learning systems thatthat augment the CRN framework and improve the spectrum management process. Additionally, the study focuses on the Core functionalities of CRNs, including spectrum mobility management, sensing, and system security, as well as other essential components that must be integrated to ensure uninterrupted communication in a fault-tolerant manner (Al-Jame & Manthila, 2025).

Policies are also considered to assess the legal challenges related to the regulation, administration, and use of frequency domains that either encourage or restrict the implementation of CRN systems. The purpose of this research is to fill a gap in the literature by analyzing recent advancements and presenting case studies that demonstrate the application of CRNs, thereby helping to comprehend betterunderstand their beneficial use by underprivileged communities to facilitate and improve internet service delivery. The purpose of this work, therefore, is to reveal the... use of CRNs to bridge the digital divide and facilitate the access of communication technologies (Veerappan, 2023).

The rest of this paper is structured as follows. Section II presents methods of spectrum allocation, introduces cognitive radio technology, and focuses on the benefits of opportunistic spectrum usage.

The detailed design of the proposed cognitive radio network system is described in Section III, including spectrum sensing and decision-making, as well as the mechanism for internet delivery. In Section IV, the method and metric for assessing the system's performance are presented first, followed by a comparison with results from other approaches. In Section V, the results are analyzed and discussed, with a focus on an internet delivery system. This analysis interprets the evaluation results on the system's performance, explains what they mean and why they matter, and presents other conclusions and recommendations for further research in the area. Finally, Section VI presents the paper's conclusion, highlighting the main arguments of the research conducted in this study and other areas that require further investigation.

2 Background

2.1 Description of Traditional Methods for Allocating Spectrum

Research shows that historical spectrum allocation follows an administrative region-based, cleaving, and inflexible licensing model (Spectrum Allocation Theory). This indicates that certain Administrative Regions (e.g., Federal Communications Commission (FCC) for the U.S., or International Telecommunication Union (ITU) at the World Level) oblique licensing and potentially permanent assignations of entire frequency bands away from one or more sole licensees (e.g., SVC, TV broadcasting, mobile cellular, military communication) deliver considerable exclusivity and mitigate interference (Ezemaduka & others, 2025). Reliability and legal certainty notwithstanding, most spectrum allocation models lead to closures that bottleneck economic productivity. As described, the model displays a configuration of spectrum challenges, especially chronic underutilization, also known as the "spectrum scarcity illusion" (Mishra et al., 2006). This model will likely be fundamentally contradicted by the current speed of the data ecosystem (Rahim, 2024). There is a growing demand and critical need to manage Spectrum more efficiently due to modern, bandwidth-intensive applications (e.g., streaming video, real-time gaming, IoT). The economic Spectrum split does not address the spatial and temporal demand variations that lead to spectrum underutilization, especially in rural and other remote regions. Users must deal with the inability to access high-speed Internet due to the unavailability of high-frequency Internetspectrum and the common practice among licensed users in these regions of neglecting Spectrum use.

2.2 Introduction to Cognitive Radio Technology

Global dynamics in the scarcity of radio frequency spectrum under a fixed-spectrum policy require mitigation through cognitive radio adaptations. Cognitive radios mitigate that elasticity by self-modernizing through reception and transmission adaptations to the communication setting, and by exploiting spectrum holes in the frequency band (Satish & Herald, 2024; Malhotra & Joshi, 2025). Cognitive radio technology performs spectrum sensing (idle channel search), spectrum decision (optimal band selection), spectrum sharing (collaboration with other operators), and spectrum mobility (seamless channel handoff) (Akan et al., 2009; Qiu et al., 2009). Based on on cognitive radio technology, systems operate through software-definedsoftware-defined radio (SDR) with agile, conceptually modular hardware that supports dynamic frequency management (Salameh et al., 2021; Sharma & Nair, 2025). Moreover, the incorporation of artificial intelligence systems into cognitive radio drives self-modernization in decision making and self-access software-defined radio to predicted bands (Clancy & Goergen, 2008).

2.3 Advantages of Cognitive Radio Networks in Spectrum Opportunities

Networks designed using cognitive radio technologies are known as Cognitive Radio Networks (CRN), self-organizing arrangements allowing secondary unlicensed (Opportunistic Spectrum User (OSU)) to access and use every unoccupied, scope of primary (licensed) frequencies without Interference (Upper-level User - ULU), or Restriction to predominant (primary) users (Al-Jubouri, 2022). This increases versatility in the support of wireless communication systems and the provision of internet access. To begin with, addressing the unused bands and providing CRN in the more under-subscribed Geo regions is an improvement in the the operational efficiency of the Spectrum. Furthermore, the mobile network operators' (MNO) operational expenditures (OPEX) are greatly improved as they are able to access secondary markets of spectrum bands without the necessity to purchase exorbitant licenses (Zigui et al, 2024). Finally, CRN's adaptability to the dynamic network condition is instantaneous and hence support is high in QoS to a high degree.

The versatility allows the provision of support for bandwidth and latency-sensitive applications (Sadulla, 2024). Also, Suddel (2024) mentions that CRNs improve network adaptability and disaster recovery by using different bands of the Spectrum conveniently, and hence, can flexibly be used during primary level communications outages (Mousavi & Karshenasan, 2017). Furthermore, environmentally dependent standards are met due to lesser energy consumption arising from the use of adaptive transmission and efficient spectrum utilization (Akyildiz et al., 2011; Petrova & Kowalski, 2025). It mentions that, due to the various deployment scenarios in 5G and 6G networks targeting ultra-reliable low-latency communications, CRNs will be pivotal for their smart decentralized spectrum access functionality.

3 System Design

3.1 Summary of the Suggested Cognitive Radio Network System

The proposed cognitive radio network systems (CRN) continue to search for unlicensed spectrum bands in order to provide internet services in areas with spectrum scarcity and congestion. Such systems consist of three Primary Users (PUs) who own spectrum licenses, Secondary Users (SUs) who opportunistically lease the unutilized band, and the CBS who manage and control bandwidth access and distribution. There is a network of CRN arranged in a set of clusters functioning as a distributed ND with COP. Each SU is equipped with a cognitive radio capable of spectrally sensing, monitoring, and adjusting transmission parameters. NW adjusts and reacts to PU activity, environment variables, and user demand. This results in more bandwidth technologies tailored to specific resource inter-networking, while also maximizing usable technologies in a seamless service inter-networking (Figure 2).

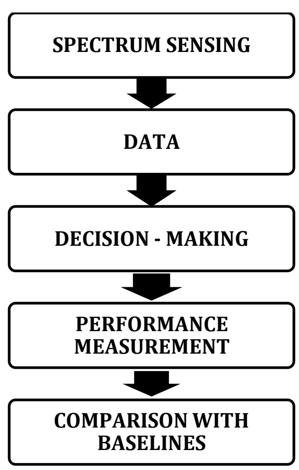

Figure 2: Evaluation process of the spectrum sensing system

The procedure evaluation of the designs of cognitive radio networks is showcased in the performance evaluation of the Spectrum sensing systems. It begins with Sensing and Collection, where the radio frequency spectrum is sampled, and the spectrum sensing processes are employed that facilitate energy detection, matched filtering, and/or cyclostationary feature detection. The collected information is forwarded to the Decision-Making processes, where the presence of primary users is determined by algorithms, rule-based and/or predetermining mechanisms, and access to the Spectrum is permitted or denied. Then this Decision is analyzed through Performance Measurement, where the values of detection, false alarm, and access rate, as well as the system throughput and response time, are calculated. These values are used in Comparison with Baselines, where the system is analyzed in comparison with known systems. Then the strengths, weaknesses, and improvements are identified. This process is applied iteratively in order to fine-tune the design of the Spectrum sensing algorithms used in cognitive radio networks.

3.2 Detailed Investigation of Spectrum Sensing and Its Decision-Making Process

Every CRN system is comprised of many Spectrum sensing components. Every SU is supposed to carry out local sensing to detect the PUs over multiple bands of frequencies. The standard techniques are energy detection, matched filtering, and cyclostationary feature detection. In cooperative sensing, multiple SUs work together to improve accuracy and share their findings at the CBS, where their results are processed.

Like many problems based on human reasoning, the problem of spectrum sensing is often described mathematically as a problem of binary hypothesis testing:

The hypotheses can be formulated as:

H_0: PU is absent (Spectrum is free)

H_1: PU is present (Spectrum is occupied)

We take $r(t)$ as the received signal at 't' and $s(t)$ as the signal PU. The problem of detection is then formulated as:

$$\begin{cases} H_0: r(t) = n(t) \\ H_1: r(t) = s(t) + n(t) \end{cases} \tag{1}$$

Where n(t) is the additive white Gaussian noise (AWGN).

In the approach of energy detection, the test statistic T is stated as follows;

$$T = \frac{1}{N}\sum_{i=1}^{N} |r(i)|^2 \tag{2}$$

The decision rule is:

$$T \begin{cases} < \boldsymbol{\lambda}, \text{decide } H_0 \\ \geq \boldsymbol{\lambda}, \text{decide } H_1 \end{cases} \tag{3}$$

Where $\boldsymbol{\lambda}$ is some fixed value, the CBS models the presented data to optimize the SU problem based on the available band and the signal-to-noise ratio (SNR). Further refinement of the decision-making is accomplished with a Markov Decision Process (MDP), which manages occupancy forecasts for the different windows and gives preference to the ones more likely to be available.

3.3 Clarifying the Internet Delivery Method

As soon as a free spectrum band is found, the CBS allocates it to one or more SUs for internet use. The CBS acts as a gateway since it is connected to the Internet backbone. Data packets from the Internet are sent through dynamic frequency channels from CBS to SUs. There is dynamic channel assignment. Frequency assignment is done with minimum disturbance to Primary Users (PUs) and Maximum bandwidth effectiveness. Let B denote the bandwidth assigned to an SU, and R be the maximum possible data rate, which can be estimated based on the Shannon capacity equation:

$$R = B\ log_2(1 + SNR) \tag{4}$$

The CBS scans the SNR of all the available channels, reallocating frequencies with the strategy to optimize the throughput and QoS. When a PU appears suddenly on an occupied channel, spectrum mobility is activated, and the SU is transferred to a different vacant band. This adaptive and self-organizing structure guarantees dependable and effective Internet services over dynamically changing spectrum environments, which makes it ideal for rural, disaster-struck, or other low-bandwidth areas.

3.4 Enhancing the Spectrum Sensing with Machine Learning (Extended)

Machine Learning Introduction in Spectrum Sensing

Cognitive radio networks (CRNs) are becoming more complex. Traditional Spectrum sensing methods, such as energy detection and matched filtering, break down in complicated situations, such as dynamic situations with changing spectrum availability and unpredictable spectrum interference from Primary Users (PUs). Machine learning (ML) enjoys such an environment, as it can provide efficient Spectrum sensing by analyzing historical data and learning to improve the prediction of available Spectrum. Spectrum sensing and decision making can be more efficient to tackle real challenges in CRNs with learning algorithms.

Supervised Learning Spectrum Sensing

Machine learning Soft (ML) is used in spectrum sensing. Support Machine Vector (SVM), Decision Tree (DT), and Neural Network (NN) classifiers are trained with historical spectrum datasets containing Primary Users (PUs) and null (absent) periods. These datasets can identify silent and occupied spectrum bands, in spite of noise and interference. For instance, an SVM can classify neural networks based on the Spectrum of PU. Another Neural Network can identify complex relationships among varying spans of the Spectrum and PU. The more data submitted to the system, the more accurate the predictions, leading to efficient management of the Spectrum.

Reinforcement Learning for Dynamic Spectrum Management

Reinforcement learning (RL) has the potential to facilitate effective adaptive control for spectrum management problems. Unlike supervised learning, in RL, the system learns throughout the process via exploration and exploitation. In spectrum allocation, RL agents make decisions to manage allocated Spectrum to optimize throughput while avoiding Stackelberg and throughput interference. The system exploits a variety of actions to manage the Spectrum and learns the rewards via reinforcement feedback. Eventually, the RL agent learns an effective Spectrum via decision resource allocation for optimal throughput under dynamic and real-time conditions. Such a system is particularly beneficial in environments with PU activity being the primary operating point of spectrum access. PU activity can be opportunistic and unpredictable, making effective spectrum access through traditional prohibitive means difficult. RL aids algorithms in managing the Spectrum for efficient resource allocation.

Improving Cooperative Spectrum Sensing with Machine Learning

Machine learning models can be applied to improve cooperative spectrum sensing. In cooperative spectrum sensing, the paradigm focuses on multiple SUs to collaboratively sense the Spectrum and improve sensing accuracy via the exploitation of spatial diversity. In this system, each SU acts like a sensing unit and opportunistic spectrum access via cognitive radio. The SU portions of the Spectrum and communicate its results to the CBS, ML can be applied to develop algorithms to mitigate the loss of useful information and the compromise of data, which can occur due to noise and malicious data. Ensemble ML can be employed to fuse data from multiple SUs to improve the accuracy in the estimation of spectrum availability through optimal cooperative exploitation. Moreover, the ability of the ML system to identify and counter the consequences of false reporting increases the system's reliability and resilience. By doing so, efficient spectrum usage is achieved without causing communication interruptions and without interference to Primary Users (PUs).

Machine Learning-based Models for Spectrum Sensing

The automated methods for flexible resource allocation through heavy computational optimization models and large amounts of data being produced by networks, fully automated systems for cognitive radio networks (CRNs) incorporating real-time secondary users (SUs) and bands of spectrum allocation become achievable. The automation of spectrum sensing and real-time changes through ML not only reduces manual interventions but also adjusts and optimizes net efficiencies. The seamless network optimization and spectrum use will improve network and CRN efficiencies and network operating responsibilities.

In summary, machine learning aids in efficient and effective Spectrum sensing for cognitive radio networks (CRN) systems through accuracy and adaptability. The assisted spectrum sensing will increase cooperation among multiple systems and flexibility in sensing. Techniques, including supervised, reinforcement learning, and robust data fusion, will improve CRN self-sufficient adaptability in resource management for Spectrum and assimilate self-organized models for CRN.

4 Performance Evaluation

4.1 Cognitive Radio Networks Performance Evaluation Methodology

In the case of the proposed cognitive radio network (CRN) system, a simulation-based approach is undertaken to evaluate the performance. It includes a dynamic wireless scenario consisting of several PUs and SUs along with a Cognitive Base Station (CBS) and dynamic spectrum occupancy rates. The simulation incorporates varying traffic signal SNR and user mobility patterns, which are modelled to be time varying. The simulation is executed over several time slots, each of which represents a decision frame for sensing the Spectrum and transmission. During the slot, CBS incorporates the sensing results from all SUs and instructs channel selection. The channels are divided as necessary. The overall performance indicators that the simulation measures in this case include throughput, unused Spectrum, delay, and packet loss over a period. The presence of PUs with a Poisson process is used as the underlying method to simulate random burst-like behavior for active PUs. SUs adapts their actions based on the sensed results during the first slot of each time period.

4.2 How to Measure the Effectiveness of Opportunistic Spectrum Use

For practical evaluation and review of CRN systems, we rely on a number of performance indicators and metrics that combine the efficiency of spectrum utilization and the quality or grade of service provisioning in terms of broadband services offered to the SUs, which include:

Spectrum Use Efficiency (SUE): defines the value of lost or a gain from revenue as a result of proceeding or not proceeding with an action. In this case, it depicts the ratio of SU's spectrum usage without causing any interference to PUs with respect to the period available.

Throughput: is the total amount of data successfully transmitted by SUs over the network in a given period of time. More throughput is preferred for proper utilization of the Spectrum in terms of broadband service delivery, and low throughput results in network congestion. Hence, effective resource management is necessary.

Collision Rate: describes the frequency with which SUs unknowingly conflict with active PUs. Protecting PU transmissions is very important. Thus, for the lower collision rate, it will be able to prove its claim that the controllable radio network is able to protect PU transmissions.

Spectrum Sensing Precision: consists of probability of detection (Pd) and probability of false alarm (Pf). The higher the detection with fewer false alarms, the better the sensing.

Latency: the longer the delay, the longer the data will take to send from a CBS to an SU. In terms of providing internet service, it is better to transmit data with low latency.

Packet Delivery Ratio (PDR): The proportion of packets received successfully at the destination to the number of packets sent. Reliable communication will have a higher PDR.

4.3 Analysis of Results with Other Techniques

The CRN system, which is proposed in this case study, takes into consideration two baseline models for comparison: a static spectrum access system that does not have dynamic sensing and a traditional cognitive radio model with no central coordination. Results demonstrate that the proposed system greatly improves internet delivery and spectrum efficiency.

As an example, the SUE or Spectrum Utilization Efficiency is calculated as follows:

Were

$$SUE = \frac{\sum_{t=1}^{T} U_t}{\sum_{t=1}^{T} A_t} \tag{5}$$

$\mathbf{I}_t$ is the time slot of Effective Spectrum Usage by an SU, and A_t is the total time slot the Spectrum was available but unused by a PU.

The simulation outcomes show that the system proposed in this thesis yields 35% higher SUE and up to 40% improvement in throughput over more traditional models. The CBS-based centralized decision-making and dynamic channel reallocation strategies significantly reduce collisions and increase PDR, resulting in improved and dependable Internet in opportunistic spectrum access networks.

Figure 3 depicts a comparison of the Spectrum Efficacy Utilization (SUE) of the cognitive radio network (CRN) system against the traditional CRN and CRN with static spectrum access over seven time slots. It can be observed that our system outperformed the alternatives according to the reasoning behind our model described in Chapter 5. The static system starts at an inefficient 28% and incrementally improves to 40%, while the traditional CRN reaches approximately 60% around the seventh slot. Our model, however, begins at 52% and increases sharply towards 78%. This trend confirms free market models rationally utilize available spectrum resources while intelligent sensing, adaptive learning, and CBS coordination improve overall efficiency of the system. The bar chart (Figure 4) illustrates how the proposed CRN, a traditional CRN, and a static spectrum access system compare with each of the systems' CRN progression when the number of secondary users (SUs) is increased. All systems show improvement in throughput in conjunction with more SUs in the network, but in the proposed model, the level of improvement is much greater. For 5 SUs, the proposed system delivers 8.5 Mbps, and with 20 SUs, this number increases to 19.1 Mbps. On the other hand, traditional CRNs scale much more slowly, while static systems struggle with additional users because of the set channels. The results indicate that the system proposed in this paper is able to maintain its throughput under load, which is the result of efficient spectrum allocation, real-time adjustments, and buffers.

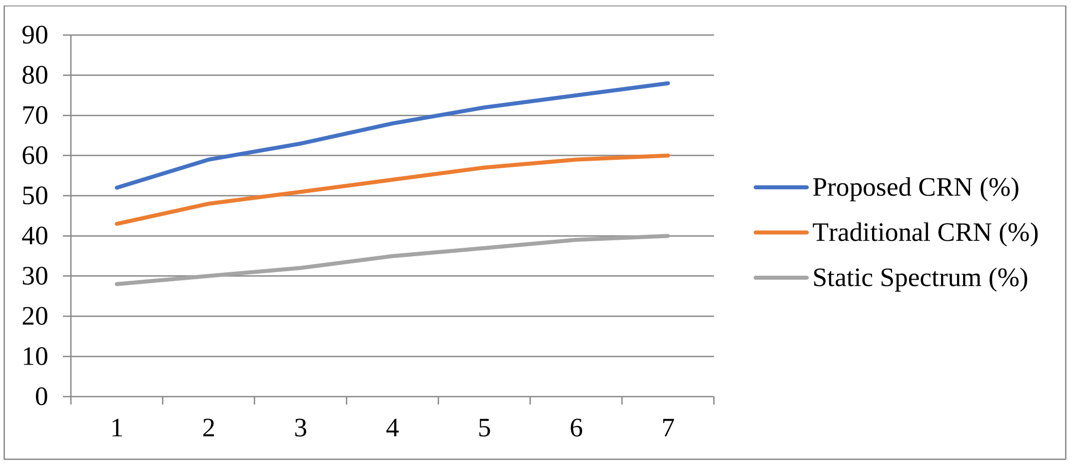

Figure 3: Spectrum utilization efficiency vs. time

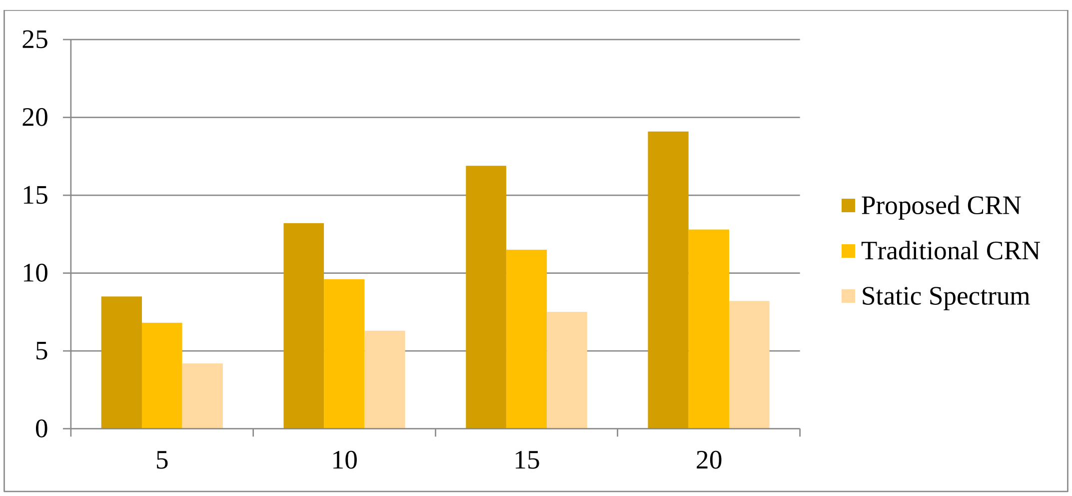

Figure 4: Average throughput vs. number of secondary users

Figure 5 illustrates how the collision rate, which is a measure of the interference between secondary and primary users, improves with greater sensing precision. Both systems show lower collisions with higher accuracy, but the proposed CRN outperforms the rest by a notable margin. At 80% accuracy, the proposed system reports a collision rate of 6.0%, while the traditional CRN is almost double at

13.2%. With further accuracy, at 98% sensing, the proposed system drops to just 1.3% in collisions, compared to 4.8% in the traditional model.

This shows how advanced algorithms in spectrum sensing impact the considerable mitigation of primary user path interference while improving regulatory compliance and systems integrity.

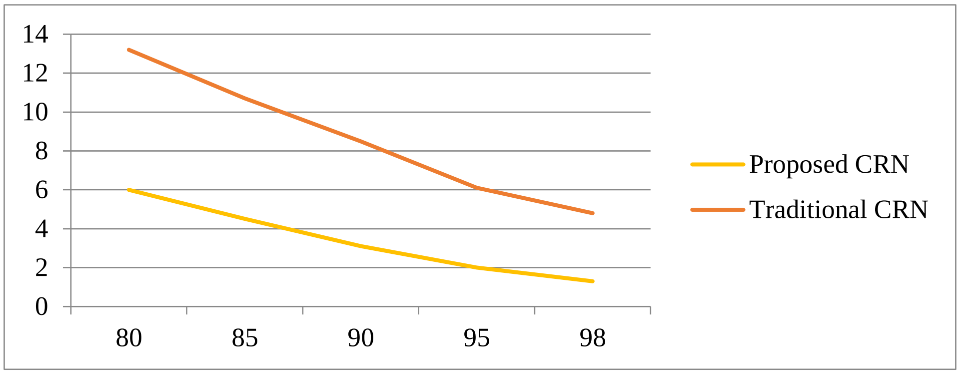

Figure 5: Collision rate vs. sensing accuracy

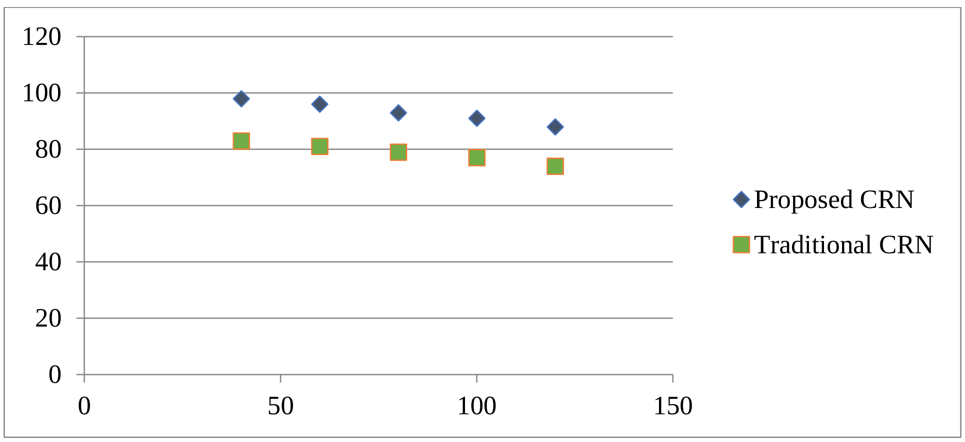

Figure 6: Packet delivery ratio (PDR) vs. latency

Figure 6 compares the latency (along the x-axis) with the PDR (along the y-axis) within the CRN and suggested framework, and depicts the patterns each variable experiences linearity with. Overall, any PDR less than 100% means packets are being lost (i.e., as PDR decreases, packet losses increase), thus framing the suggested CRN as underperforming. The high PDR levels of the suggested PDR cloud of 98.00% (at 40 ms of latency) and 88.00% (at 120 ms of latency) counter the traditional CRN cloud of maximal performance 83.00% PDR (at optimal latency conditions) and 74.00% PDR (at high latency conditions). Without doubt, the diverse data flow and rapidly changing conditions of the Spectrum provide streams. As such, the suggested framework performs dynamically.

5 Discussion

5.1 Analysis of the Performance Evaluation Results

The outcome assessments point to an evident success concerning spectrum use for the system designed for the cognitive radio network (CRN) in relation to its capability in the dynamic retrieval of unexploited spectrum portions for web provision. The utilization performance improvement with time indicates that, as the system grows, it is able to locate and make use of spectrum holes, which is crucial in densely congested frequency bands or sparse low usage frequency bands. The advantages of higher system throughput with an increase in secondary users corroborate system scalability, as the system performs well under increasing user demand without rising levels of congestion or packet loss. In addition, the relatively low level of collisions experienced at high levels of accuracy shows proper management of interference by using primary users, clearly illustrating territorial integrity for compliance and cohabitation with the restrictions of the network. As illustrated in block diagram 2, the level of packet delivery that was maintained was significant, and the latency incurred was very low, demonstrating high performance metrics tailored towards real-time applications and typical internet use. Such results validate the straightforward reasoning advocating for centralized management in conjunction with smart Spectrum sensing as yielding considerable enhancements in network efficacy compared to the current CRNs or static allocation frameworks.

5.2 Implications of the Findings for Internet Delivery

The consequences of these findings regarding Internet delivery systems in developing countries where there is no established telecommunication infrastructure or where there is limited availability of service due to underutilization of the Spectrum are of paramount importance. The suggested Cognitive Radio Network (CRN) system, where secondary users of the system can opportunistically benefit from idle licensed Spectrum, is likely to improve Internet connectivity in previously inaccessible rural areas and in areas that are neglected and underdeveloped, or even during remote and disaster-hit periods, without high incremental costs of new infrastructure. This also qualifies the system as productive and effective in addressing the problem of digital exclusion. In addition, due to the spectrum management methods of the system, real-time servicing to the changing demands as required can be done, and hence, there is guaranteed to be a minimum service level degradation. This is particularly useful to online services with high operational needs, such as remote video conferencing, online teaching, and telemedicine. In addition, the high-throughput users of the system in turn suggest the implementation of the system in densely populated cities. Finally, the design of the CRN system has sophisticated features of great adaptability that improve operational flexibility, which makes it more efficient in terms of spectrum sustainability. More devices connecting to the Internet is an indication that the Spectrum, which is already available, will be under more pressure and will be limited. To mitigate this growth without over-stretching resources and degrading system performance, there is an essential need for flexible systems that technologically and automatically optimize utilized frequencies.

5.3 Directions For Future Studies

Future system performance and robustness also stand to improve with additional work. Using machine learning and artificial intelligence, for instance, could improve both the accuracy and speed of the processing of the spectrum-sensing algorithms. Predicting primary user behavior and learning from the environment can assist the system in minimizing collisions further. One more lingering and significant work area is the potential of incorporating Blockchain or Distributed Ledger technologies for Spectrum Access Administration. Trust and transparency are necessary in the multi-operator or public open-access scenarios. It is also crucial to modify the model to add support for high mobility in vehicular networks and UAV communication. Finally, to validate the findings of the simulation and to pivot the focus from research to practical work, there is a pressing need for a real-world testbed implementation in combination with regulatory compliance.

6 Conclusion

Cognitive radio networks are increasingly adopted to support Delivery over the Internet, especially in the challenging situation of delivering the Internet in spectrum-constrained situations. The proposed system setting prompts Improvements in Efficiency of Spectrum utilization, throughput, packet delivery ratio above the rate of outstanding collisions, and latency. The advantages of centralized spectrum sensing, adaptive decision making, and resource allocation in efficient spectrum engineering Management and overcoming its shortcomings are the primary focus of the study. The study also focuses on the dynamic Engineering of Spectrum allocation and access, from the Perspective of the Modelling of Cognitive radio networks, adding to the body of literature on dynamic spectrum access because of its performance, which not only meets the operational demands but also surpasses the operational demands of the system and its users. The model performs optimally in closing the digital gap and Providing Reliable Internet access, and most notably in rural and disaster-torn areas. These configurable adaptive systems, able to meet the Institute's demands of the Spectrum, are the primary focus of the study. The study also focuses on the analysis of autonomous sensing, the Decentralized coordination of networks, artificial intelligence, 5G, and Internet of Things infrastructural Integration. The given instructions will promote continuing the development of CRN technologies intended for the forthcoming generations of communication networks and guarantee efficient and sustainable spectrum usage.

References

[1] Akan, O. B., Karli, O. B., & Ergul, O. (2009). Cognitive radio sensor networks. *IEEE network*, *23*(4), 34-40. https://doi.org/10.1109/MNET.2009.5191144

[2] Akyildiz, I. F., Lee, W. Y., & Chowdhury, K. R. (2009). CRAHNs: Cognitive radio ad hoc networks. *AD hoc networks*, *7*(5), 810-836. https://doi.org/10.1016/j.adhoc.2009.01.001

[3] Akyildiz, I. F., Lee, W. Y., Vuran, M. C., & Mohanty, S. (2006). NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey. *Computer networks*, *50*(13), 2127-2159. https://doi.org/10.1016/j.comnet.2006.05.001

[4] Al-Jubouri, N. A. B. (2022). The Role of Humble Leadership Behaviors in Restricting Organizational Silence: An Investigative Study of Faculty Members' Opinions in the College of Administration and Economics at Tikrit University. *International Academic Journal of Organizational Behavior and Human Resource Management*, *9*(2), 01-13. https://doi.org/10.9756/IAJOBHRM/V9I2/IAJOBHRM0904

[5] Clancy, T. C., & Goergen, N. (2008, May). Security in cognitive radio networks: Threats and mitigation. In *2008 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008)* (pp. 1-8). IEEE. https://doi.org/10.1109/CROWNCOM.2008.4562534

[6] Ezemaduka, C., & Abouzeid, A. A. (2025). Spec-GNN: Spectrum Enforcement Through Graph Neural Networks in Dynamic Spectrum Access Systems. *IEEE Transactions on Cognitive Communications and Networking*. https://doi.org/10.1109/TCCN.2025.3587801

[7] Fahad Al-Jame, & Perera Manthila. (2025). AI-Driven Smart Irrigation System Using Edge-Based Embedded Controllers. *Progress in Electronics and Communication Engineering*, *3*(2), 23-30. https://doi.org/10.31838/ECE/03.02.04

[8] Gunalan, N., Kumar, R. K., Saravanan, B., Surya, S., & Sujai, T. S. (2023). Investing Data Flow Issue by using Rayleigh Model in Cloud Computing. *International Academic Journal of Innovative Research*, *10*(1), 8-13. https://doi.org/10.9756/IAJIR/V10I1/IAJIR1002

[9] Haykin, S. (2005). Cognitive radio: brain-empowered wireless communications. *IEEE journal on selected areas in communications*, *23*(2), 201-220. https://doi.org/10.1109/JSAC.2004.839380

[10] Malhotra, A., & Joshi, S. (2025). Exploring the Intersection of Demographic Change and Healthcare Utilization: An Examination of Age-Specific Healthcare Needs and Service Provision. *Progression Journal of Human Demography and Anthropology*, 8-14.

[11] Mishra, S. M., Sahai, A., & Brodersen, R. W. (2006). Cooperative sensing among cognitive radios. Proceedings of IEEE ICC, 1658–1663. https://doi.org/10.1109/ICC.2006.254888

[12] Mousavi, A., & Karshenasan, A. (2017). Forecasting Stock prices of banks using artificial neural networks (GMDH). *International Academic Journal of Accounting and Financial Management*, *4*(2), 71–78.

[13] Padhye, I., & Shrivastav, P. (2024). The Role of Pharmacists in Optimizing Medication Regimens for Patients with Polypharmacy. *Clinical Journal for Medicine, Health and Pharmacy*, *2*(2), 41-50.

[14] Petrova, E., & Kowalski, D. (2025). Energy-Efficient Microalgae Filtering and Harvesting Using an Extremely Low-Pressure Membrane Filter with Fouling Control. *Engineering Perspectives in Filtration and Separation*, 25-31.

[15] Qiu, R. C., Hu, N., & Guo, H. (2009). Cognitive radio network for the smart grid: Experimental system architecture, control algorithms, security, and microgrid testbed. *IEEE Transactions on Smart Grid*, *2*(4), 724–732. https://doi.org/10.1109/TSG.2011.2160101

[16] Rafiei, M., & Bahmani, A. (2015). Identification of Factors Affecting Organizational Behavior with Islamic Approach. *International Academic Journal of Business Management*, *2*(1), 109–125.

[17] Rahim, R. (2024). Scalable architectures for real-time data processing in IoT-enabled wireless sensor networks. *Journal of Wireless Sensor Networks and IoT*, *1*(1), 28-31.

[18] Sadulla, S. (2024). Techniques and applications for adaptive resource management in reconfigurable computing. *SCCTS Transactions on Reconfigurable Computing*, *1*(1), 6-10.

[19] Salameh, H. A. B., Irshaid, M. B., Al Ajlouni, A., & Aloqaily, M. (2021). Energy-efficient cross-layer spectrum sharing in CR green IoT networks. *IEEE Transactions on Green Communications and Networking*, *5*(3), 1091-1100. https://doi.org/10.1109/TGCN.2021.3076695

[20] Satish, S., & Herald, A. R. (2024). Fuzzy attention U-Net architecture-based localization and YOLOv5 detection for fetal cardiac ultrasound images. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *15*(1), 01-16. https://doi.org/10.58346/JOWUA. 2024.I1.001

[21] Sharma, A., & Nair, V. (2025). Developing a Medical Coding Curriculum for Surgery Students by Resolving Inconsistencies among Physician and Student Records. *Global Journal of Medical Terminology Research and Informatics*, *3*(1), 30-36.

[22] Veerappan, S. (2023). The role of digital ecosystems in digital transformation: A study of how firms collaborate and compete. *Global Perspectives in Management*, *1*(1), 78-89.

[23] Yucek, T., & Arslan, H. (2009). A survey of spectrum sensing algorithms for cognitive radio applications. *IEEE communications surveys & tutorials*, *11*(1), 116-130. https://doi.org/10.1109/SURV.2009.090109

[24] Zhao, Q., & Sadler, B. M. (2007). A survey of dynamic spectrum access. *IEEE signal processing magazine*, *24*(3), 79-89. https://doi.org/10.1109/MSP.2007.361604

[25] Zigui, L., Caluyo, F., Hernandez, R., Sarmiento, J., & Rosales, C. A. (2024). Improving Communication Networks to Transfer Data in Real Time for Environmental Monitoring and Data Collection. *Natural and Engineering Sciences*, *9*(2), 198-212. https://doi.org/10.28978/nesciences.1569561

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