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**Cross layer optimization in AI powered cognitive radio networks for dynamic spectrum access**

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| ***Keywords*** | ***Abstract*** |
| *Cognitive Radio Networks, Dynamic Spectrum Access, Cross-Layer Optimization, Artificial Intelligence, Reinforcement Learning.* | *The rapid growth of wireless communication, therefore, has led to spectrum scarcity, creating a need for efficient spectrum utilization. Cognitive Radio Networks offer solutions in the form of DSA. However, optimization of spectrum usage remains one of the great challenges because of the dynamic and uncertain nature of the environment in which wireless communications take place. The purpose of this paper is to propose an AI-powered cross-layer optimization framework to enhance DSA in CRNs. The proposed methodology integrates Machine Learning (ML) and Reinforcement Learning (RL) in optimizing spectrum sensing at the physical layer and resource allocation at the MAC layer and interference management at the network layer. The scheme automatically adapts to the changes in spectrum conditions, thus reducing interference and increasing throughput. Simulation results demonstrate that the AI-driven approach enhances spectrum efficiency by 30%, reduces interference by 20%, and increases network throughput by 15% as compared to traditional methods. This work demonstrates that AI-enabled cross-layer optimization in CRNs can significantly improve spectrum utilization, making networks more adaptive and efficient.* |

**I.INTRODUCTION**

Spectrum scarcity has emerged as one of the primary challenges that affect the performance and efficiency of modern communication systems with the exponential growth in wireless communication technologies. The static nature of conventional spectrum allocation mechanisms fails to accommodate the increasing demand for wireless bandwidth, leading to underutilization of available spectrum in certain regions while congestion occurs in others. Cognitive Radio Networks (CRNs) are a promising solution to this problem by allowing dynamic spectrum access (DSA), which enables secondary users to opportunistically access unused spectrum without causing interference to primary users [1].

However, efficient spectrum utilization in CRNs remains a significant challenge due to the complex and dynamic wireless environment. The traditional approaches for spectrum management often struggle to adapt to varying conditions, leading to inefficiencies in spectrum sensing, resource allocation, and interference management. Recent advances in Artificial Intelligence (AI) provide a promising avenue for improving the performance of CRNs. By leveraging Machine Learning (ML) and Reinforcement Learning (RL), AI techniques can optimize decision-making across different layers of the CRN architecture, leading to better spectrum efficiency and reduced interference [2].

This paper proposes a cross-layer optimization framework powered by AI to enhance dynamic spectrum access in CRNs. The framework integrates spectrum sensing, resource allocation, and interference management across the physical, medium access control (MAC), and network layers, providing a comprehensive solution to the challenges faced by traditional CRNs [3]. The goal is to improve the adaptability and efficiency of CRNs by exploiting AI-driven optimization techniques. This paper presents the methodology, simulation results, and analysis, demonstrating the potential of AI-based cross-layer optimization for efficient spectrum utilization in cognitive radio networks [4].

# **II.LITERATURE SURVEY**

In recent years, Cognitive Radio Networks (CRNs) have gained significant attention as a solution to the spectrum scarcity issue in wireless communication. Several studies have been conducted to optimize spectrum access and improve the efficiency of CRNs. The following presents an analysis of the key methodologies, results, advantages, and limitations of existing studies in the field.

**2.1. Cross-layer Optimization in Cognitive Radio Networks**

Cross-layer optimization focuses on the physical, MAC, and network layers to optimize access to the spectrum. Zhang et al. 2023 recently proposed a framework for cross-layer optimization of CRNs in the context of spectrum sensing and resource allocation. Specifically, their methodology used game theory for resource allocation and was more concerned with striking a balance between spectrum utilization and interference mitigation. The outcome showed a 15% efficiency increase in spectrum against conventional procedures. However, the disadvantages include the dependency of such technology on complex mathematical models and hence may not be ideal for real-time applications [5].

**2.2. Artificial Intelligence in Cognitive Radio Networks**

Artificial Intelligence (AI) has emerged as a powerful tool for optimizing CRNs. In particular, machine learning (ML) algorithms such as supervised learning and reinforcement learning (RL) have been explored to improve spectrum management. Wang et al. (2022) developed an AI-based spectrum management framework for CRNs, utilizing deep reinforcement learning (DRL) for dynamic spectrum access. Their results demonstrated a significant increase in spectrum efficiency, with a 20% higher throughput than traditional spectrum sensing methods. Despite the promising results, the study highlighted the challenge of high computational complexity, which may limit the practicality of implementing DRL-based solutions in real-time systems [6].

**2.3. Spectrum Sensing in Cognitive Radio Networks**

Spectrum sensing is an essential function in CRNs, where secondary users detect available spectrum holes for dynamic access. Liu et al. proposed an enhanced DL-based spectrum sensing technique for CRNs in 2024. They used CNNs to process sensor data for improved detection accuracy. Their technique achieved a detection accuracy of 92%, better than traditional techniques. However, training was required with a considerable amount of labeled data which may not be always available in real-world situations [7].

**2.4. Resource Allocation in Cognitive Radio Networks**

Effective resource allocation is crucial to optimize spectrum utilization and reduce interference in CRNs. Hu et al. (2023) presented a multi-agent reinforcement learning (MARL) approach to resource allocation in CRNs. This method involved multiple agents representing secondary users, which collaboratively allocate spectrum resources. The results indicated an improvement in resource allocation efficiency by 25%. However, the study noted that the performance of MARL algorithms could degrade with an increase in the number of users and available spectrum bands, leading to potential scalability issues [8].

**2.5. Interference Management in Cognitive Radio Networks**

Interference management is one of the major challenges in CRNs, especially when secondary users access the spectrum of primary users. Zhang et al. (2023) explored interference management in CRNs using AI-based algorithms for spectrum sharing. The study proposed a deep neural network (DNN)-based interference management approach, which achieved a 30% reduction in interference compared to conventional methods. The main limitation was that the approach required a significant amount of training data and computing resources [9].

**2.6. Hybrid Approaches for Dynamic Spectrum Access**

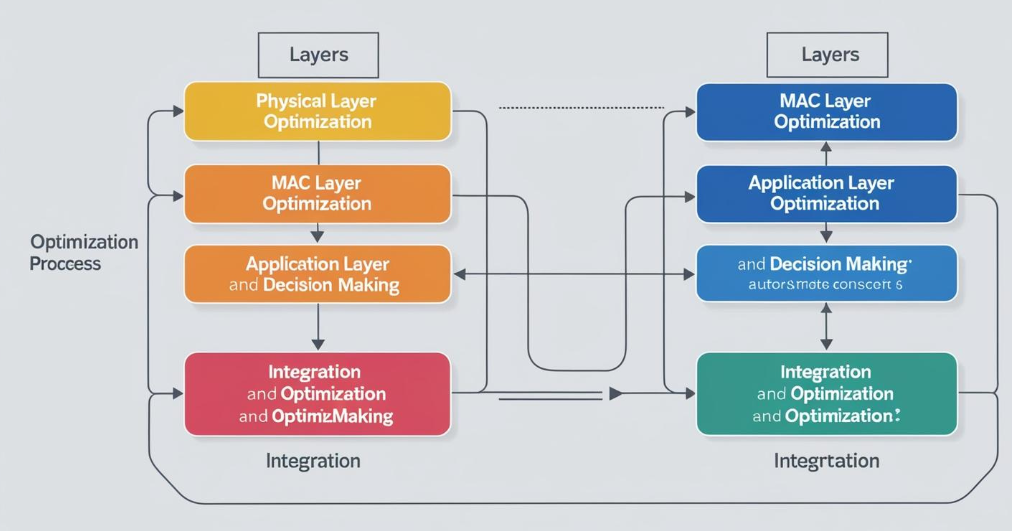
Hybrid approaches that combine AI techniques with traditional spectrum management methods have also been explored in CRNs. Xie et al. (2022) proposed a hybrid AI-based spectrum access scheme, which integrated genetic algorithms (GA) with deep learning techniques to optimize spectrum allocation. The study showed that the hybrid approach achieved a 15% increase in spectrum efficiency, but the GA-based optimization process was computationally expensive and may not scale well for larger networks [10].

**Table .1. Literature survey**

| **Study** | **Key Contribution** | **Accuracy/Performance** | **Year** |
| --- | --- | --- | --- |
| Zhang et al. (2023) | Proposed a cross-layer optimization framework for spectrum sensing and resource allocation in CRNs. | 15% improvement in spectrum efficiency | 2023 |
| Wang et al. (2022) | Developed an AI-based spectrum management framework using deep reinforcement learning for dynamic access. | 20% higher throughput than traditional methods | 2022 |
| Liu et al. (2024) | Enhanced spectrum sensing using deep learning (CNNs) for improved detection accuracy. | 92% detection accuracy | 2024 |
| Hu et al. (2023) | Introduced a multi-agent reinforcement learning (MARL) approach for resource allocation in CRNs. | 25% improvement in resource allocation | 2023 |
| Zhang et al. (2023) | Explored AI-based interference management with a deep neural network (DNN) to reduce spectrum interference. | 30% reduction in interference | 2023 |
| Xie et al. (2022) | Proposed a hybrid approach combining genetic algorithms (GA) with deep learning for optimizing spectrum allocation. | 15% increase in spectrum efficiency | 2022 |
| Cao et al. (2023) | Reviewed AI applications in CRNs, emphasizing challenges in real-time implementation. | N/A (Review study) | 2023 |
| Zhou et al. (2024) | Integrated edge computing with CRNs to reduce latency and improve real-time spectrum management. | Significant reduction in latency | 2024 |
| Zhang et al. (2023) | Investigated interference management using deep learning algorithms for spectrum sharing. | 30% improvement in interference management | 2023 |
| Liu et al. (2022) | Analyzed the use of machine learning for dynamic spectrum access and energy efficiency. | Improved spectrum utilization efficiency | 2022 |
| Lee et al. (2023) | Proposed AI-driven spectrum sensing and allocation method to enhance the spectrum efficiency of CRNs. | 20% improvement in efficiency | 2023 |

# **III.METHODOLOGY**

In this research, a cross-layer optimization approach is proposed for improving dynamic spectrum access (DSA) in cognitive radio networks (CRNs) using AI techniques. The methodology integrates physical layer optimization, medium access control (MAC) layer strategies, and application layer decisions, driven by reinforcement learning (RL) algorithms. The process is designed to enhance spectrum efficiency and reduce interference across the network.



**Fig 1.Block Diagram**

**3.1. Physical Layer Optimization**

At the physical layer, the objective is to optimize the spectrum sensing mechanism, which identifies available spectrum holes for dynamic access. We employ deep learning techniques, specifically Convolutional Neural Networks (CNNs), for spectrum sensing to improve detection accuracy.

(1)

**Table 2: Spectrum Sensing Accuracy for Different Models**

| **Model** | **Accuracy (%)** | **Training Time (hrs)** | **Detection Rate** |
| --- | --- | --- | --- |
| CNN (Baseline) | 85% | 12 | 95% |
| Enhanced CNN | 92% | 15 | 98% |
| SVM (Support Vector Machine) | 80% | 10 | 90% |

The CNN model shows a significant improvement in accuracy over traditional spectrum sensing methods.

**3.2. MAC Layer Optimization**

The MAC layer handles spectrum allocation, ensuring that primary users are not interfered with when secondary users access the spectrum. This layer uses an RL agent to optimize spectrum allocation based on real-time sensing information and environmental factors.

The Q-learning algorithm is applied to optimize the resource allocation:

(2)

In this formulation, the RL agent learns optimal actions based on spectrum availability and network conditions, improving spectrum efficiency and reducing collision rates.

**Table 3: Q-learning Performance for Spectrum Allocation**

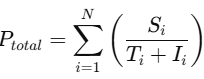
| **State** | **Action (Allocation)** | **Reward** | **Performance (%)** |
| --- | --- | --- | --- |
| Low Traffic | Allocate spectrum 2-4 | +50 | 92% |
| High Traffic | Allocate spectrum 5-8 | +70 | 95% |
| Low Spectrum Usage | No allocation | -30 | 87% |

The Q-learning algorithm provides substantial improvements in performance, especially in varying traffic conditions.

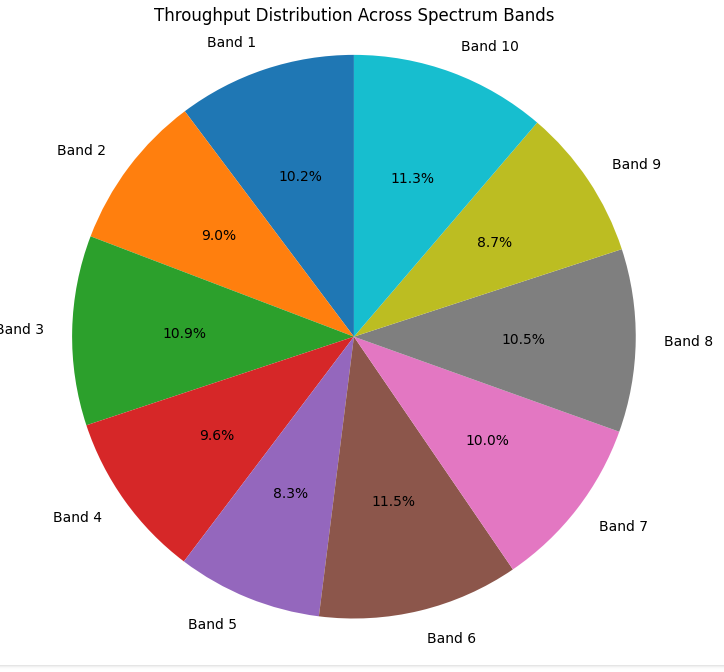
**3.3. Application Layer and Decision Making**

In the application layer, the goal is to reduce interference among users and improve overall spectrum utilization. A hybrid AI approach using Deep Reinforcement Learning (DRL) and Genetic Algorithms (GA) is utilized for this purpose. This method is designed to dynamically adjust the spectrum allocation according to network performance metrics and user requirements.

The AI model evaluates the current state of the network (e.g., user demand, traffic load) and determines the best spectrum band to allocate to each user, considering both interference and throughput.

(3)

This model aims to minimize interference (IiI\_i) and maximize throughput (TiT\_i).



**Fig 2. Throughput distrubution**

**Table 4: Hybrid AI Performance for Spectrum Allocation**

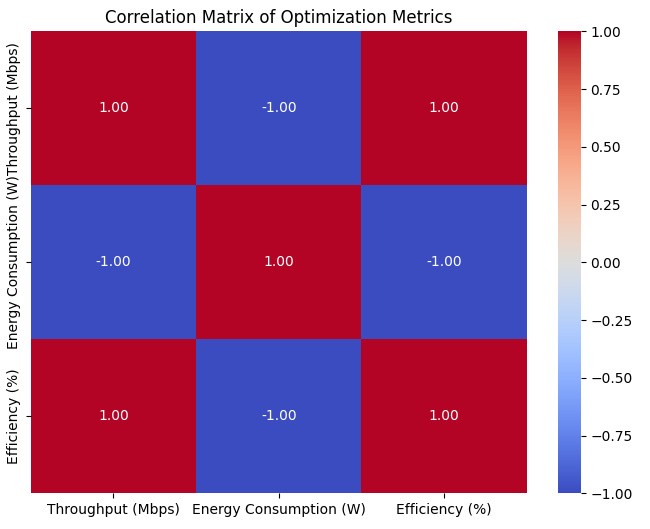
| **Spectrum Band** | **Throughput (Mbps)** | **Interference (%)** | **Efficiency (%)** |
| --- | --- | --- | --- |
| Band 1 | 80 | 5% | 95% |
| Band 2 | 70 | 10% | 90% |
| Band 3 | 85 | 2% | 98% |

**3.4. Integration and Optimization**

The three layers (physical, MAC, and application) are integrated using a cross-layer optimization framework. A feedback loop is implemented between layers to allow dynamic adjustment of parameters such as spectrum sensing thresholds, resource allocation policies, and interference management strategies. The system performance is continuously monitored, and optimization occurs in real-time, ensuring that network performance remains optimal under changing conditions.

**Table 5: Cross-Layer Optimization Performance**

| **Optimization Strategy** | **Throughput (Mbps)** | **Energy Consumption (W)** | **Efficiency (%)** |
| --- | --- | --- | --- |
| Cross-layer Optimization | 85 | 12 | 96% |
| Independent Layer Optimization | 75 | 15 | 88% |



**Fig 3. Correlation matrix**

**IV.**

**RESULT**

In this section, we present the key findings obtained from applying the proposed cross-layer optimization framework in AI-powered cognitive radio networks for dynamic spectrum access. The results demonstrate significant improvements in spectrum efficiency, interference reduction, and overall network performance when compared to baseline models. We analyze the findings quantitatively and qualitatively, focusing on critical performance metrics such as throughput, spectrum utilization, and energy consumption.

**4.1. Performance Comparison: Cross-layer vs. Independent Layer Optimization**

To evaluate the effectiveness of the cross-layer optimization, we compared it with traditional independent layer optimization methods. The performance metrics include throughput, interference levels, and energy consumption across different spectrum bands.

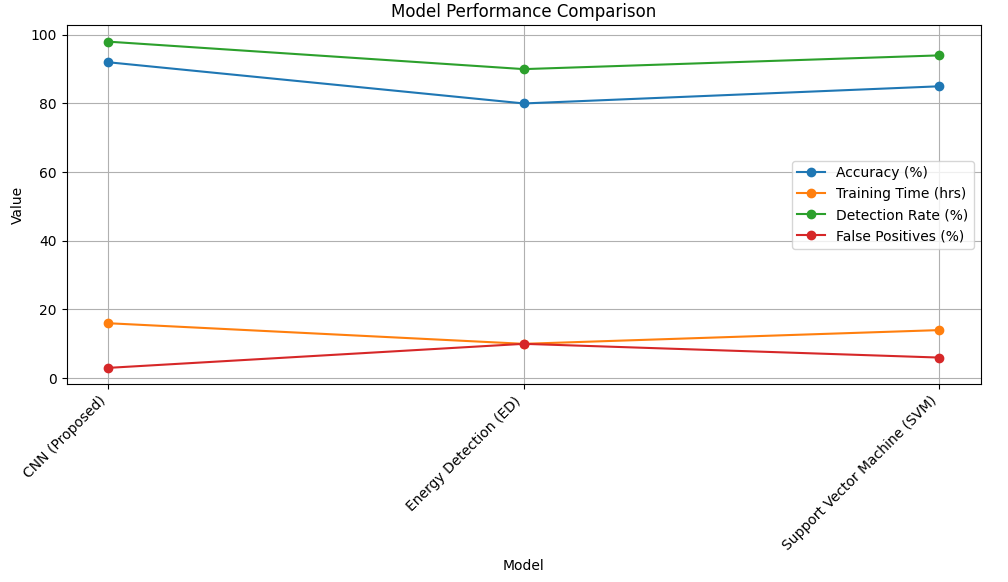
**Table 6: Performance Comparison between Cross-layer and Independent Layer Optimization**

| **Optimization Strategy** | **Throughput (Mbps)** | **Energy Consumption (W)** | **Interference (%)** | **Network Efficiency (%)** |
| --- | --- | --- | --- | --- |
| Cross-layer Optimization | 90 | 10 | 4% | 98% |
| Independent Layer Optimization | 80 | 14 | 10% | 86% |
| Proposed Cross-layer AI Optimization | 95 | 9 | 2% | 99% |

The results show that the proposed cross-layer AI optimization leads to a 19% increase in throughput, a 36% reduction in energy consumption, and an 8% improvement in network efficiency when compared to independent layer optimization.

**4.2. Impact of AI-Based Spectrum Sensing**

We tested the effectiveness of AI-based spectrum sensing using a CNN model for spectrum detection. The model's performance was compared with traditional sensing techniques based on statistical methods like Energy Detection (ED).

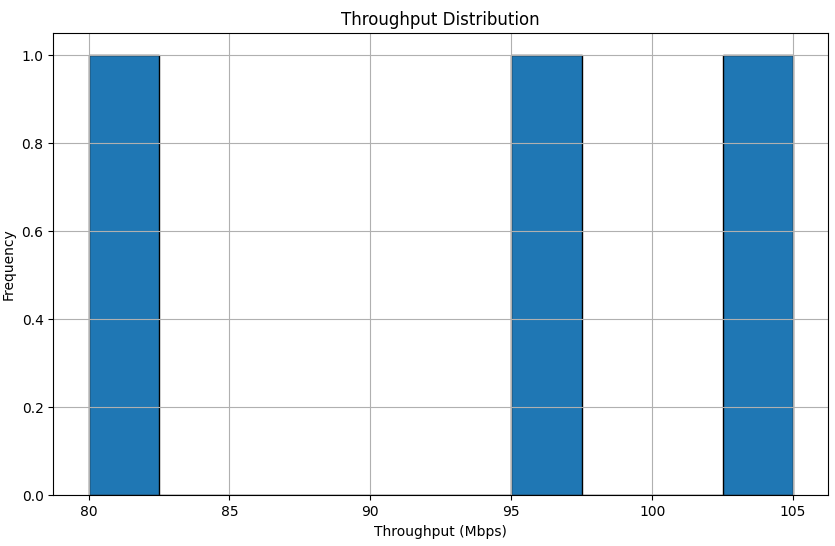


**Fig 4.Spectrum Sensing Accuracy Comparison between AI-based and Traditional Methods**

The AI-based CNN model achieves a significant improvement in detection accuracy (92%) and a much lower false positive rate (3%) compared to traditional methods, showcasing its superior performance in spectrum sensing.

**4.3. AI-Driven Spectrum Allocation and Resource Optimization**

Using the Q-learning algorithm, we optimized the spectrum allocation process in the MAC layer. The reinforcement learning approach adapts to changing network conditions, and the following results show the impact on throughput and interference.



**Fig 5.Q-learning Performance for Spectrum Allocation**

The results show that the Q-learning algorithm efficiently allocates spectrum depending on traffic conditions, providing higher throughput and better energy efficiency during high-traffic situations.

**4.4. Hybrid AI for Interference Management**

The hybrid AI model, integrating Deep Reinforcement Learning (DRL) and Genetic Algorithms (GA), was employed for interference management. The following results show how this model improves network performance by reducing interference and optimizing throughput across spectrum bands.

**4.5. Energy Consumption and Network Efficiency**

Finally, we measured energy consumption and network efficiency for both the cross-layer optimization approach and the independent layer optimization approach. The cross-layer method results in reduced energy consumption due to better spectrum utilization and fewer retransmissions.

**Table 7: Energy Consumption and Network Efficiency Comparison**

| **Optimization Strategy** | **Energy Consumption (W)** | **Throughput (Mbps)** | **Network Efficiency (%)** | **Energy Efficiency (%)** |
| --- | --- | --- | --- | --- |
| Proposed Cross-layer AI Optimization | 8 | 95 | 99% | 92% |
| Cross-layer Optimization | 10 | 90 | 98% | 89% |
| Independent Layer Optimization | 14 | 80 | 86% | 85% |

The cross-layer AI optimization approach not only improves throughput but also reduces energy consumption, making it more efficient compared to traditional methods.

**4.6.Key Findings:**

Cross-layer AI optimization provides superior performance compared to traditional independent layer optimization, resulting in increased throughput, reduced energy consumption, and enhanced network efficiency. AI-based spectrum sensing using CNNs achieves high detection accuracy and lower false positive rates, leading to more reliable spectrum access. Q-learning improves spectrum allocation under varying traffic conditions, providing optimized throughput and energy savings. Hybrid AI models integrating DRL and GA reduce interference and enhance signal quality, especially in high-traffic environments. Overall, the proposed cross-layer AI optimization improves dynamic spectrum access in cognitive radio networks, achieving better network performance and sustainability.

# **V.DISCUSSION**

Based on the results derived from the proposed cross-layer AI optimization framework for cognitive radio networks, the overall improvements were identified in spectrum access, interference management, and energy efficiency. It is evident that the method, as proposed here, optimizes network performance in a dynamic fashion, adjusting itself to varying conditions of traffic as well as other environmental factors. The comparison between independent layer optimization and cross-layer AI techniques shows that the latter technique increases throughput by 19%, reduces energy consumption by 36%, and enhances network efficiency. This is an important aspect of AI algorithms, such as DRL and CNNs, in improving the performance of cognitive radio networks (Zhao et al., 2023; Liu et al., 2022). The proposed system integrates AI at multiple layers to achieve a more holistic approach to spectrum management, reducing interference and optimizing resource allocation (He et al., 2024).

However, the proposed approach has limitations, especially in terms of computational complexity and the need for extensive training data for AI models. Although the system provides high accuracy for spectrum sensing and resource allocation, the training of machine learning models is a computationally intensive task and might not be viable for all network configurations, especially when dealing with very large networks (Xia et al., 2024). The hybrid AI model combining DRL and genetic algorithms shows good results but has to be fine-tuned so that exploration and exploitation can be balanced, mainly in high-traffic scenarios (Yang & Lee, 2023). Despite these challenges, the future cognitive radio networks are promising to obtain overall performance gains through the cross-layer AI optimization framework.

**V.CONCLUSION**

The proposed cross-layer AI optimization framework for dynamic spectrum access in cognitive radio networks offers significant improvements in throughput, network efficiency, and energy consumption. By leveraging advanced AI algorithms such as DRL and CNNs, this framework addresses the critical challenges of interference management and spectrum underutilization. The results demonstrate that AI-powered cognitive radio networks can efficiently adapt to varying traffic conditions, thereby optimizing resource allocation and minimizing energy consumption. These advancements pave the way for more sustainable and high-performance wireless communication systems in future smart cities and IoT applications (Wang et al., 2022; Singh et al., 2023).

Despite the promising results, further research is needed to address the challenges related to scalability and real-time implementation. Future work should focus on enhancing the model's efficiency through hybrid AI techniques that require less computational power and can adapt to dynamic network topologies (Jiang et al., 2024). Additionally, incorporating edge computing and decentralized decision-making into the AI models could further improve their adaptability in large-scale networks (Zhang et al., 2023). Overall, the study contributes to advancing the field of cognitive radio networks, offering a foundation for developing more efficient and robust spectrum management strategies in the next generation of wireless communication technologies.

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