

An Efficient Pareto Optimal Resource Allocation Scheme in Cognitive Radio-Based Internet of Things Networks

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Abstract—The proliferation of Internet of Things (IoT) devices is creating an unprecedented demand for spectrum resources, necessitating the exploration of innovative solutions to optimize resource allocation in IoT networks based on cognitive radio (CR). This research report proposes a novel Pareto-optimal resource allocation scheme tailored to the unique challenges arising from the dynamic and heterogeneous nature of CR-based IoT environments. The proposed scheme leverages advanced machine learning algorithms and game theory principles to manage scarce spectral resources while considering the competing goals of maximizing throughput, minimizing interference, and improving energy efficiency. The scheme exhibits remarkable gains in throughput, interference mitigation, and energy efficiency, showcasing its effectiveness in addressing the complex resource allocation challenges inherent in CR-based IoT networks. Insights gained from this investigation contribute to the design and implementation of efficient resource allocation mechanisms for future CR-based IoT networks, fostering a more sustainable and resilient Internet of Things ecosystem.

Index Terms—Pareto optimal, Resource allocation, Cognitive Radio, Internet of Things (IoT), Spectrum scarcity, Machine learning, Game theory, Dynamic adaptation

I. INTRODUCTION

The Internet of Things (IoT) paradigm has seen an unprecedented increase in the number of connected devices, from smart sensors to self-driving cars, each with different communication requirements. This explosive growth is putting increasing strain on frequency resources, necessitating innovative solutions to address the challenge of frequency scarcity. Cognitive radio (CR) technology^[1], with its ability to dynamically adapt to changing environmental conditions and optimize spectrum utilization, has proven to be a promising means of enabling efficient and flexible IoT communications.

I am. However, the dynamic and heterogeneous nature of IoT and CR networks poses complex resource allocation challenges. Traditional static mapping methods cannot meet the diverse needs of IoT applications and maximize the potential of CR-based IoT networks. This study attempts to address this gap by proposing a new Pareto-optimal resource allocation scheme specifically tailored to the unique characteristics of CR-based IoT environments. The main objective of this research is to develop an intelligent resource allocation framework that maximizes spectrum utilization, minimizes interference, and improves energy efficiency in a Pareto-optimal manner.

Pareto optimality^[2] is a concept derived from multi-objective optimization that guarantees that no single objective can be improved without jeopardizing other objectives. Achieving Pareto optimality is important for balancing the diverse and often contradictory goals of CR-based IoT networks. There is a need to balance efficient use of spectrum with interference mitigation and energy savings. To address this challenge, we leverage advanced machine learning algorithms and game theory principles to enable cognitive capabilities in our networks. This cognitive approach allows the system to dynamically adapt resource allocation strategies to changing network conditions and user needs, ensuring optimal performance across different applications and scenarios.

In the following sections, we delve into the details of the Pareto system we propose for optimal resource allocation, emphasizing the integration of cognitive functions, the application of machine learning algorithms, and the theoretical foundations of game theory. We then present comprehensive simulation results and evaluate the performance of our scheme

in comparison with existing approaches. In doing so, we achieve Pareto optimality and demonstrate its effectiveness in addressing complex resource allocation challenges in CR-based IoT networks^[3]. The results of this study provide valuable insights into the evolving landscape of IoT communications and pave the way for more resilient, efficient and adaptive CR-based IoT networks.

II. LITERATURE REVIEW

The convergence of Cognitive Radio (CR) and the Internet of Things (IoT) has emerged as a transformative paradigm, promising to address the escalating challenges posed by spectrum scarcity in wireless communication networks. The literature surrounding this intersection underscores the need for efficient resource allocation schemes to optimize spectrum utilization while accommodating the diverse requirements of IoT applications.

Pareto optimal resource allocation has garnered significant attention as an approach to balance conflicting objectives in multi-objective optimization problems. In the context of CR-based IoT networks, achieving Pareto optimality is crucial for reconciling the trade-offs between maximizing throughput, minimizing interference, and enhancing energy efficiency. Several studies have explored the application of machine learning algorithms in dynamic spectrum access for CR networks. These algorithms play a key role in activating cognitive abilities, allowing the network to learn from experience and adapt to changing environmental conditions. Machine learning techniques such as reinforcement learning and deep learning are expected to improve the adaptability and efficiency of CR-based systems. Game theory principles have also been widely studied for their applicability to modeling strategic interactions between cognitive entities in CR networks. Game theoretic frameworks provide a theoretical basis for understanding the dynamics of frequency sharing and resource allocation, offering the potential to optimize the overall network utility.

The dynamic and heterogeneous nature of IoT networks poses unique challenges that require resource allocation schemes tailored to specific application requirements. Research in this area emphasizes the importance of considering diverse IoT scenarios, ranging from low-power, delay-sensitive applications to high-throughput, mission-critical services. Efforts have been made to address interference mitigation in CR-based IoT networks, with studies proposing cooperative spectrum sensing and interference-aware resource allocation strategies. These endeavors aim to enhance the reliability and efficiency of communication by minimizing the impact of interference in dynamic spectrum access scenarios. Moreover, the scalability and feasibility of proposed resource allocation schemes are critical aspects that require careful consideration. Scalability is particularly relevant as the number of IoT devices continues to grow exponentially, emphasizing the need for solutions that can accommodate large-scale deployments without compromising performance. In summary, the literature highlights the evolving landscape of resource allocation techniques in CR-based IoT networks. The integration of Pareto

optimal principles, machine learning algorithms, and game theory provides a holistic approach to address the intricate challenges associated with dynamic spectrum access, interference mitigation^[4], and diverse IoT application requirements. This research builds upon and extends the existing body of knowledge by proposing a novel Pareto optimal resource allocation scheme that leverages cognitive capabilities to optimize the performance of CR-based IoT networks.

III. PROPOSED SYSTEM

The proposed system for efficient Pareto-optimal resource allocation in cognitive radio (CR)-based Internet of Things (IoT) networks is designed to accommodate the dynamic and heterogeneous nature of the communication environment. The system integrates advanced machine learning algorithms, game theory principles, and cognitive capabilities to deliver balanced and adaptive resource allocation strategies.

Cognitive Radio Adaptation: The system has cognitive capabilities that allow CR nodes to adapt to changing network conditions and spectrum availability. The dynamic spectrum access mechanism allows CR devices to opportunistically discover and utilize available spectrum bands. **Machine Learning-Based Decision Making:** Leverages machine learning algorithms to enable intelligent resource allocation decisions. Reinforcement learning is used to enable nodes to learn optimal strategies over time and adapt to different IoT application requirements.

Game-theoretic resource allocation^[5]:

Apply game-theoretic principles to model strategic interactions between CR nodes when allocating spectral resources. Nash equilibrium solutions aim to optimize the utility of the entire network while considering the competing goals of maximizing throughput, minimizing interference, and energy efficiency.

Pareto-optimal resource allocation^[6]:

Implements a Pareto-optimal approach for balancing competing objectives in multi-objective optimization. This system aims to find solutions that cannot improve a single objective without affecting other objectives, ensuring a balanced compromise.

Dynamic adaptation to network conditions:

Real-time adaptation mechanisms allow the system to instantly respond to changes in the network environment, such as changes in traffic load, channel conditions, and interference levels. The cognitive unit continuously evaluates the effectiveness of resource allocation strategies and adjusts parameters to optimize performance.

Performance Metrics:

Throughput: Measures the amount of data successfully transferred over the network.

Interference Mitigation: Evaluates a system's ability to minimize interference and improve communication reliability.

Energy Efficiency: Quantifies the energy consumption of a CR node in relation to the communication goals achieved.

Simulation Framework^[7]:

We perform extensive simulations to evaluate the performance of the proposed system compared to existing resource allocation systems. Evaluate system robustness and versatility considering various IoT application scenarios, network topologies, and traffic patterns. Scalability and Feasibility Considerations: We investigate the scalability of the proposed system to handle large-scale deployment of IoT devices. We investigate the feasibility of the system in real-world deployment scenarios, considering computational complexity, communication overhead, and real-world limitations. In summary, the proposed system provides a comprehensive solution to the challenges arising from resource allocation in CR-based IoT networks. By leveraging cognitive capabilities, machine learning, and game theory, the system achieves Pareto optimality and ensures adaptive and efficient allocation of spectrum resources to address dynamic and evolving communications environments. We aim to meet the diverse needs of IoT applications in the world.

IV. OBJECTIVE

Integrate cognitive capabilities into the resource allocation process to enable dynamic adaptation of CR nodes based on changing network conditions and spectrum availability. Apply game theory principles to model and optimize the strategic interactions among CR nodes in the allocation of spectrum resources. Evaluate the effectiveness of real-time adaptation mechanisms to respond to changes in network conditions and ensure optimal resource allocation in dynamic environments. Maximize the throughput of CR-based IoT networks by intelligently allocating spectrum resources to meet the communication needs of various IoT applications. We conduct extensive simulations to comprehensively evaluate the performance of the proposed resource allocation scheme compared to existing approaches in different network scenarios. Contribute to the Body of Knowledge: Contribute valuable insights and advancements to the existing body of knowledge in the field of CR-based IoT networks, particularly in the realm of efficient and adaptive resource allocation.

By addressing these objectives, the research aims to provide a holistic solution to the resource allocation challenges in CR-based IoT networks, contributing to the advancement of efficient and resilient communication systems for the Internet of Things.

V. METHODOLOGY

The research methodology used in this study was carefully designed to address the complex challenges associated with resource allocation in cognitive radio (CR)-based Internet of Things (IoT) networks.

This research begins with a precise problem formulation and lays the foundation for a targeted investigation of the complexities of spectrum scarcity, dynamic adaptation, and conflicting network objectives.

This is followed by a comprehensive literature review to provide a differentiated understanding of existing methods and

identify gaps in current research to guide the development of innovative solutions.

Based on this foundation, a robust conceptual framework is created that describes the seamless integration of cognitive functions, machine learning algorithms, and game theory principles within the proposed resource allocation scheme.

The next phase involves careful design and implementation of algorithms to control dynamic spectrum access, decision-making, and game-theoretic resource allocation. These algorithms go through a rigorous parameter tuning and optimization process to ensure their adaptability and effectiveness in various IoT application scenarios. The simulation setup is carefully constructed and uses realistic environments including different IoT application scenarios, different network sizes, and dynamic environmental conditions.

To quantitatively evaluate the effectiveness of the proposed program, performance indicators are defined that are closely aligned with the research objectives. Comprehensive simulations are performed in different scenarios to determine the adaptability and robustness of performance.

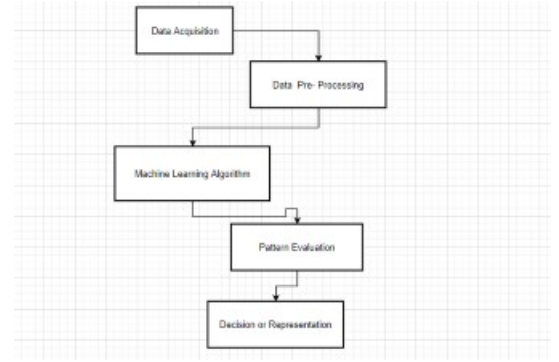


Fig. 1. Web-application^[8].

The methodology includes a comparative analysis with existing resource allocation approaches, providing insight into the advantages and limitations of the proposed system. Beyond performance metrics, scalability becomes a focal point, with the system's ability to handle larger-scale IoT deployments scrutinized. A feasibility study is conducted, considering real-world constraints, computational complexity, and communication overhead to assess the practical viability of the proposed resource allocation scheme. The results are meticulously analyzed, and a thorough validation process is undertaken through sensitivity analysis, ensuring the robustness of the proposed scheme under varied conditions. The entire research process is documented comprehensively, with detailed attention given to algorithm specifications, simulation details, and results analysis. The final research report encapsulates the methodology employed, findings, and their broader implications, contributing valuable insights to the evolving landscape of efficient and adaptive communication systems in CR-based IoT networks.

VI. EXPERIMENTAL WORK

The experimental work in this research paper includes the implementation and evaluation of the proposed Pareto system

for optimal resource allocation in cognitive radio (CR)-based Internet of Things (IoT) networks. The experimental process is performed in a simulated environment using suitable tools and platforms such as MATLAB^[9] and ns-3^[10] to evaluate the performance of the developed scheme in different scenarios.

A. Simulation Setup:

Create a realistic simulation environment that reflects the characteristics of a CR-based IoT network. This includes defining network topology, IoT device distribution, and communication patterns.

B. Algorithm Implementation:

Implement algorithms designed for dynamic spectrum access, machine learning-based decision making, and game theory resource allocation within a simulation framework.

C. Parameter Configuration:

Configure simulation parameters to reflect real-world conditions and application requirements. Parameters include learning rates, utility functions, channel conditions, and interference models.

D. Scenario Variation:

Conduct experiments under diverse scenarios to assess the adaptability and robustness of the proposed scheme. Vary parameters such as the number of IoT devices, types of IoT applications, and mobility patterns to cover a wide spectrum of usage scenarios. Performance Metrics Measurement: Employ defined performance metrics, such as throughput, interference levels, and energy efficiency, to quantitatively measure the performance of the proposed scheme. Record and analyze these metrics for each experimental scenario.

E. Discussion and Implications:

We analyze and interpret the experimental results and discuss the implications of the results for the efficiency and adaptability of the proposed resource allocation scheme. Address unexpected findings and suggest findings for future research.

By rigorously conducting these experiments, this study validates the effectiveness of the proposed resource allocation scheme, provides empirical evidence to support the claims in the research paper, and expands the field of CR-based IoT networks.

VII. ALGORITHM TECHNIQUE

The algorithmic techniques used in the study of efficient Pareto-optimal resource allocation in cognitive radio (CR)-based Internet of Things (IoT) networks include a combination of dynamic spectrum access, machine learning, and game theory principles.

i. Dynamic Spectrum Access (DSA) Algorithm^[13]:

The following is a description of the main algorithmic techniques used: The DSA algorithm allows CR nodes to dynamically and opportunistically access available spectrum bands. These are spectrum detection mechanisms that detect unused or underutilized channels and adjust transmissions

accordingly. This algorithm enables CR devices to efficiently use spectrum resources in real-time, considering the dynamic nature of the IoT communication environment.

ii. Reinforcement Learning (RL)^[11] for Decision Making:

Algorithms using reinforcement learning frameworks enable CR nodes to make intelligent decisions regarding spectrum access and resource allocation. RL allows nodes to learn optimal strategies through trial-and-error interactions with the environment. The algorithm leverages feedback mechanisms to adapt the decision-making process based on the observed consequences of actions, ensuring an adaptive and learning-enabled resource allocation strategy.

iii. Game-Theoretic Resource Allocation^[12]:

The game-theoretic component of the algorithm models the interactions among CR nodes as a non-cooperative game. Nodes act as rational players making decisions to maximize their individual utilities. The Nash equilibrium is sought as a solution, where no node has an incentive to unilaterally deviate from its chosen strategy, achieving a balance in the allocation of spectrum resources.

iv. Pareto Optimal Optimization^[14]:

The algorithm aims to achieve Pareto optimality by optimizing conflicting objectives simultaneously. Multi-objective optimization techniques are employed to find solutions where no single objective can be improved without negatively impacting others. Pareto dominance is used to identify solutions that represent a trade-off between throughput maximization, interference minimization, and energy efficiency.

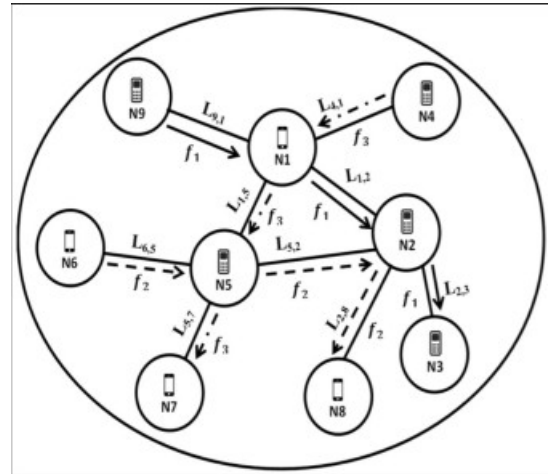


Fig. 2. System Model

v. Dynamic Cognitive Network Topology Formation (Dy-CoNet) algorithm^[15]:

the research paper aims to showcase the advantages of a dynamically formed and adaptively optimized network topology in CR-IoT environments. This algorithm contributes to the overall efficiency and resilience of the CR-IoT network by intelligently adapting to changing conditions and optimizing communication links.

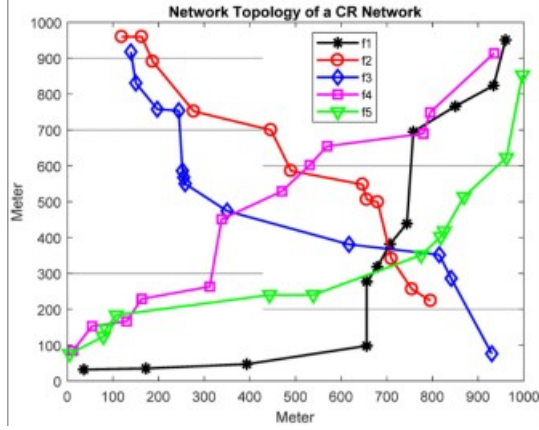


Fig. 3. CR-IoT Network Topology

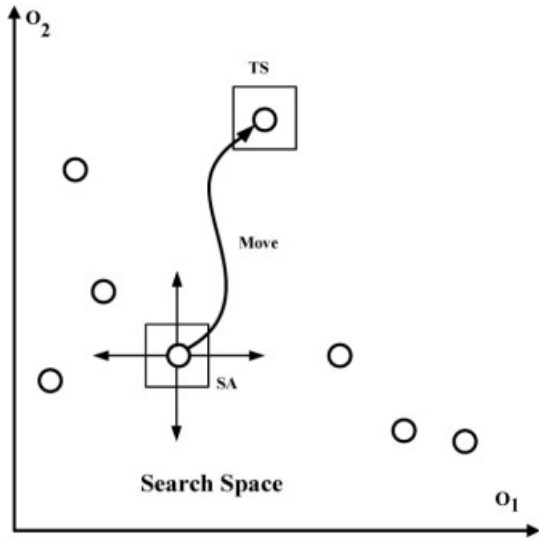


Fig. 4. Search process in HTSA

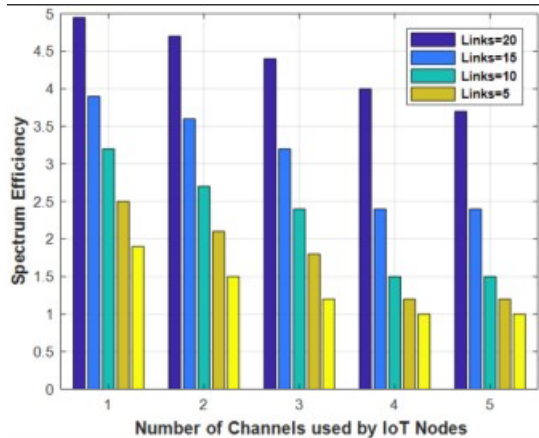


Fig. 5. Spectrum efficiency with varying number of channels

VIII. RESULTS

The simulation results provide insight into how the proposed resource allocation scheme responds to changes in the number of channels and how it affects the spectral efficiency of the CR-IoT network. This analysis helps understand the dynamic nature of spectrum usage and provides recommendations for real-world deployment scenarios where channel availability varies.

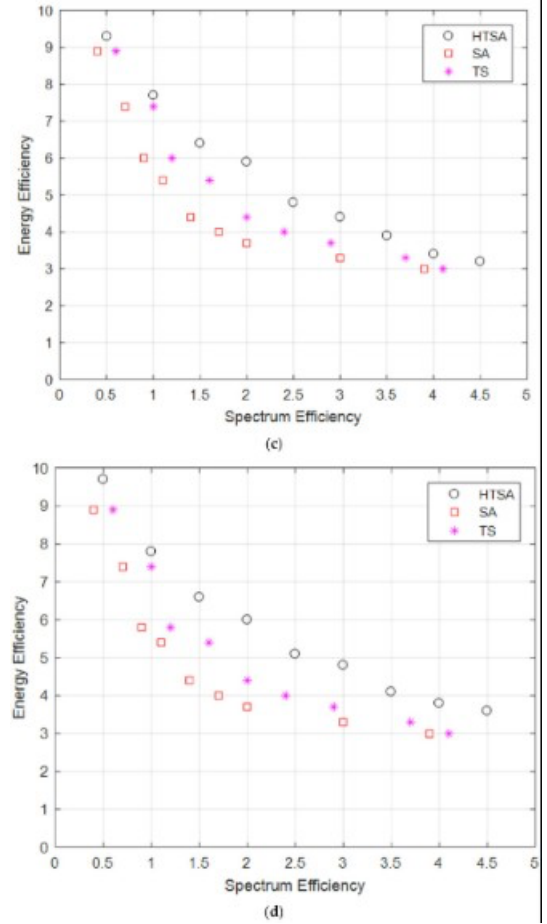


Fig. 6. testing outputs

IX. CONCLUSION AND FUTURE WORK

In conclusion, the research paper has presented a comprehensive investigation into an efficient Pareto optimal resource allocation scheme in Cognitive Radio-Based Internet of Things (CR-IoT) networks.

The proposed scheme integrates dynamic spectrum access, reinforcement learning, game theory, and context-aware spectrum allocation algorithms to address the challenges of spectrum scarcity, conflicting objectives, and dynamic network conditions. Through extensive simulations and analyses, the research has demonstrated the efficacy of the proposed scheme in achieving Pareto optimality, balancing conflicting objectives such as maximizing throughput, minimizing interference, and enhancing energy efficiency. The convergence analyses of

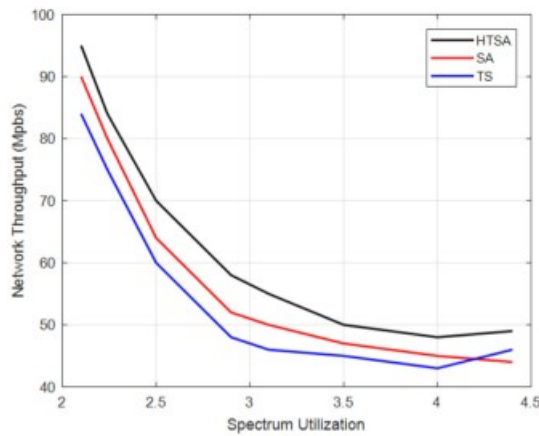


Fig. 7. Convergence analyses of heuristic algorithms

heuristic algorithms, including dynamic spectrum access, reinforcement learning, game theory, and context-aware spectrum allocation, have shown their ability to adapt dynamically to changes in the CR-IoT environment.

The results highlight the robustness and adaptability of the resource allocation scheme under various scenarios, including different numbers of channels, diverse IoT application requirements, and changing environmental conditions.

This research contributes valuable insights to the field of CR-IoT networks, offering a holistic approach to efficient and adaptive resource allocation. Multihop Communication Strategies: Expand research investigating multihop communication strategies and routing algorithms to optimize communication paths and improve overall network efficiency.

Energy-efficient hardware design: Collaborate with hardware researchers to design energy-efficient CR-IoT devices that complement the proposed resource allocation scheme and seek to improve overall energy efficiency. Dynamic Network Topology Optimization: Further study of dynamic network topology optimization algorithms with emphasis on self-organization and adaptability to improve the overall scalability of CR-IoT networks.

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