Empowering Wireless Connectivity: Advancing UAV-RIS SWIPT for Dynamic Energy and Information Transmission

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By

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DECLARATION

I hereby certify that the work, which is being presented in the report/thesis, entitled ”Empowering Wireless Connectivity: Advancing UAV-RIS SWIPT for Dynamic Energy and Information Transmission” , in fulfillment of the requirement for the award of the degree of Bachelor of Technology and submitted to the institution is an authentic record of my/our own work carried out during the period May-2023 to August-2023 under the supervision of Dr. Binod Prasad. I also cited the reference about the text(s)/figure(s)/table(s) from where they have been taken.

Dated: **Signature of the candidate**

This is to certify that the above statement made by the candidates is correct to the best of my knowledge.

Dated: **Signature of supervisor**

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I am highly indebted to Dr. Binod Prasad , for his esteemed mentorship, and for allowing me to freely explore and experiment with various ideas in the course of making this project a reality. The leeway I was given went a long way towards helping cultivate a genuine hunger for knowledge and keeping up the motivation to achieve the best possible outcome. I can genuinely say that this Bachelor's Thesis Project (BTP) made me explore many areas of machine learning that are new to me, and kindled an interest to further follow up on some of those areas. Moreover, the semi-successful completion of this project has brought with it great satisfaction and more importantly, confidence in my ability to produce more high-quality non-trivial artificial intelligence systems that can make a difference in the real-world. I would like to sincerely express my gratitude to this prestigious institution for providing me and my colleagues with the opportunity to pursue this BTP. It is an honor to be able to work on such an important academic project under the guidance and support I am provided with. I am grateful for the resources and facilities provided by this institution, which have been instrumental in enabling me to conduct my research and complete this project. Moreover, I deeply appreciate the efforts of my professors in mentoring and fairly evaluating our works.

Aditya Pote

Abstract

In the field of wireless communication, the combination of Unmanned Aerial Vehicles (UAVs) with Reconfigurable Intelligent Surfaces (RIS) is a significant step forward. This research explores the use of Simultaneous Wireless Information and Power Transfer (SWIPT) mechanisms within this setting.

UAV-RIS systems use advanced surfaces and passive reflectors to improve communication quality, even in challenging conditions like Non-Line-of-Sight (NLOS) situations. More than just communication, these systems can also capture and use ambient energy while sending information,

making them sustainable and efficient. Instead of traditional methods, we've applied soft computing techniques to dynamically allocate RIS elements. This ensures the best balance between energy efficiency and communication quality.

We conducted thorough analyses and simulations to understand factors that affect performance, including signal transmission and reflection properties. This research doesn't just present theories; it provides practical ways to enhance both energy harvesting and signal transmission. In summary, our study envisions a future where wireless communication isn't just about staying connected, but also about innovation, flexibility, and longevity.

Keywords: Unmanned Aerial Vehicles (UAVs), Reconfigurable Intelligent Surfaces (RIS), Wireless Communication, Energy Efficiency, Simultaneous Wireless Information and Power Transfer (SWIPT)

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List of Acronyms

DDPG	Deep Deterministic Policy Gradients
DRL	Deep Reinforcement Learning
GA	Genetic Algorithm
ML	Machine Learning
MSE	Mean Squared Error
PU	Primary User
RIS	Reconfigurable Intelligent Surface
RL	Reinforcement Learning
SNR	Signal to Noise Ratio
SWIPT	Simultaneous Wireless Information and Power Transfer
UAV	Unmanned Aerial Vehicle
Eh	Energy Harvested By Energy harvesting Group
Et	Energy used by Signal Transmission group
SNR_T	Transmitted SNR at UT

1 Introduction

This chapter offers an overview of the subject matter by presenting background information on UAV-aided RIS Communications. Emphasizing the potential of simultaneous wireless information and power transfer (SWIPT) in these systems, the chapter delves into the motivation behind exploring optimization strategies, such as genetic algorithms, to enhance the efficiency and performance of UAV-RIS systems.

1.1 Introduction

The contemporary landscape of wireless communication technologies is rapidly evolving, responding to the ever-increasing demand for enhanced communication quality. While traditional communication systems have been instrumental in establishing the foundational architecture, they frequently grapple with challenges such as spectral efficiency, energy consumption, and adaptability in dynamic environments. This is particularly evident in scenarios with Non-Line-of-Sight (NLOS) conditions, where traditional systems struggle to maintain reliable connections. A groundbreaking solution to these challenges is the integration of Unmanned Aerial Vehicles (UAVs) and Reconfigurable Intelligent Surfaces (RIS), which promises a transformative shift in the wireless communication paradigm [1,2].

UAVs, popularly known as drones, have transcended their initial recreational and surveillance applications. Recognized for their versatility, UAVs are now making significant inroads into areas like agriculture, delivery, and notably, communication. The inherent mobility and adaptability of UAVs make them an invaluable asset in enhancing wireless communication, especially in challenging terrains or areas with obstructions leading to NLOS conditions. RIS, on the other hand, offers a transformative approach to wireless communication. By introducing dynamic configurability, RIS can actively shape radio wavefronts, optimizing communication quality and even turning obstructions into advantages.

1.2 Background

While the idea of employing UAVs in wireless communications has been around for a while, their synergy with RIS, especially when combined with the SWIPT mechanism, offers a fresh perspective and an array of new possibilities [1]. Zhang et al.'s seminal work has elucidated the benefits of this integration, introducing an energy harvesting methodology that capitalizes on the capabilities of SWIPT in UAV-RIS systems [1]. Simultaneous information transfer and energy harvesting, achieved through this integration, hold the potential to revolutionize wireless communication systems, ensuring both efficiency and sustainability.

Achieving a harmonious balance between energy harvesting (EH) and information transmission is vital for UAV-aided RIS communication systems. This research delves deep into this challenge, employing advanced optimization techniques and genetic algorithms, all the while standing on the shoulders of giants in the field who have laid the foundational research.

1.3 Motivation

The integration of UAV and RIS, bolstered by the SWIPT mechanism, has the potential to be a revolutionary force in wireless communication systems [1]. This study aims to go beyond the boundaries of current knowledge, offering innovative solutions that transcend the limitations of traditional communication systems. By leveraging cutting-edge optimization techniques and drawing inspiration from foundational works by researchers like Zhang et al. [1], this study envisions a future where wireless communication is efficient, sustainable, and supremely adaptable.

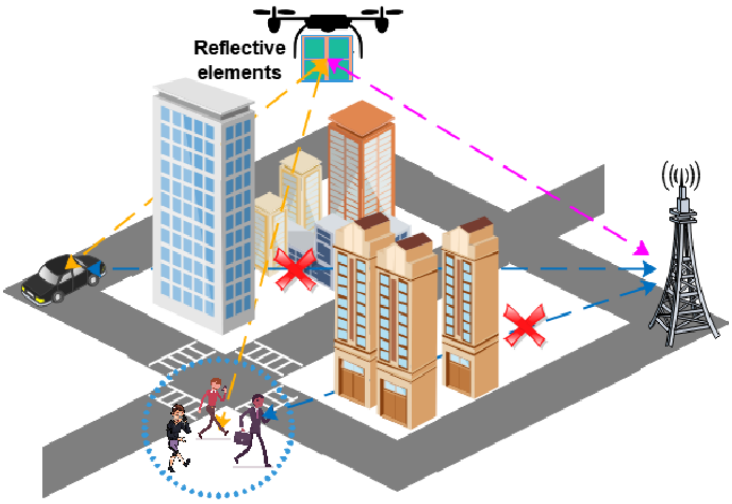

Figure 1.1: Depiction of UAV-RIS enhancing communication in NLOS conditions.

The figure above illustrates how the UAV-RIS system can enhance communication, particularly in Non-Line-of-Sight (NLOS) conditions. NLOS refers to situations where the transmission path between the transmitter and receiver is obstructed, typically by buildings or other physical barriers. In traditional communication systems, NLOS conditions can severely degrade signal quality. However, with the integration of UAVs and RIS, signals can be intelligently reflected and directed to ensure consistent and clear communication, even in challenging environments.

In today's interconnected world, seamless and uninterrupted wireless communication is not just a luxury—it's a necessity. As urban landscapes become denser and remote regions seek better connectivity, conventional systems face increasing challenges in delivering consistent quality. This is particularly pronounced in NLOS scenarios. Enter the UAV-aided RIS communication system. By merging the adaptability of UAVs with the reflective prowess of RIS, this system offers amplified signal strength, reduced interference, and the ability to turn challenges like NLOS into advantages. Additionally, with the integration of the SWIPT mechanism, the system achieves a dual feat—exceptional communication quality and simultaneous energy harvesting. This promises a future where UAVs can be powered in transit, minimizing downtimes and maximizing efficiency.

2

Literature Review on UAV-aided RIS Communications

This chapter delves into the extensive body of research dedicated to UAV-aided RIS Communications, with a particular emphasis on spectrum sensing and the SWIPT mechanism. We explore the foundational literature, tracing the evolution of methodologies, techniques, and paradigms in this domain. The chapter also identifies research gaps and highlights the significance of the current study in the broader context of wireless communications.

2.1 Reconfigurable Intelligent Surfaces (RIS)

Reconfigurable Intelligent Surfaces (RIS) have emerged as a transformative technology in wireless communication. These surfaces consist of passive elements with electromagnetic properties that can be reconfigured in real-time. The essence of RIS lies in its ability to actively shape the radio wavefront, thereby promising significant enhancements in wireless communication by mitigating common challenges like signal attenuation, multipath propagation, and interference [3].

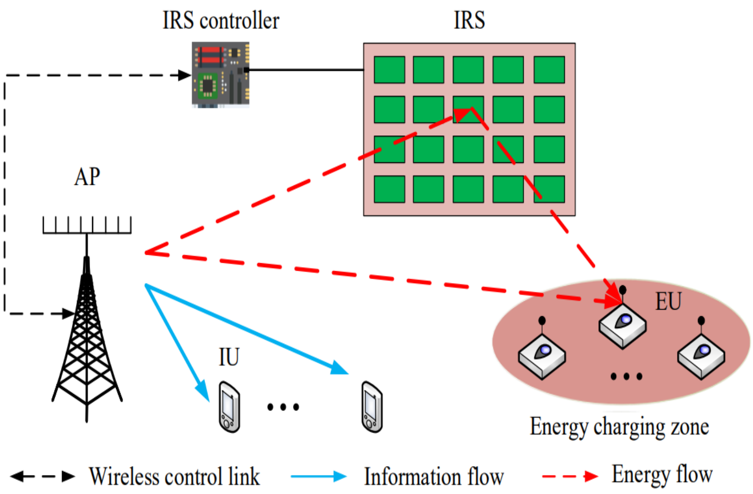

Figure 2.1: Basic RIS

2.1.1 Evolution of RIS

The inception of RIS can be traced back to metamaterials—engineered materials designed with properties not found in nature. These materials exhibit unique interactions with electromagnetic waves, which led to the conceptualization and eventual realization of RIS in practical communication scenarios [4, 5]. Over the years, the evolution of RIS from a mere concept to a pivotal tool in wireless communications has paved the way for enhanced data rates, broader coverage, and superior energy efficiency [3].

2.2 Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles, or drones, have transcended their initial military-centric applications to become integral parts of various industries. Their potential utility in the field of communication, especially, has garnered significant attention [6].

2.2.1 UAVs in Communication

UAVs present a dynamic, mobile, and highly flexible platform for wireless communication. They can be swiftly deployed, marking their significance in scenarios like disaster recovery, remote area connectivity, and adaptive network scenarios. Serving as airborne base stations, relays, or mobile user equipment, UAVs have the potential to revolutionize network coverage and capacity, delivering services even in the most challenging terrains [7].

2.3 Integration of UAV and RIS: UAV-RIS Systems

Merging the distinctive advantages of UAVs and RIS forms a robust solution for the future of wireless communication. The mobility and adaptability of UAVs, when combined with the radio wave shaping capabilities of RIS, set the stage for an unparalleled communication experience.

2.3.1 UAV-RIS: A New Communication Paradigm

The combination of UAV and RIS is not just an integration but a reinvention of wireless communication possibilities. The inherent adaptability of RIS paired with the mobility of UAVs can cater to real-time communication needs, adapting to fluctuating channel conditions, diverse user distributions, and dynamic energy requirements. Such systems promise to deliver robust, efficient, and adaptive communication even in the most challenging scenarios [8, 9].

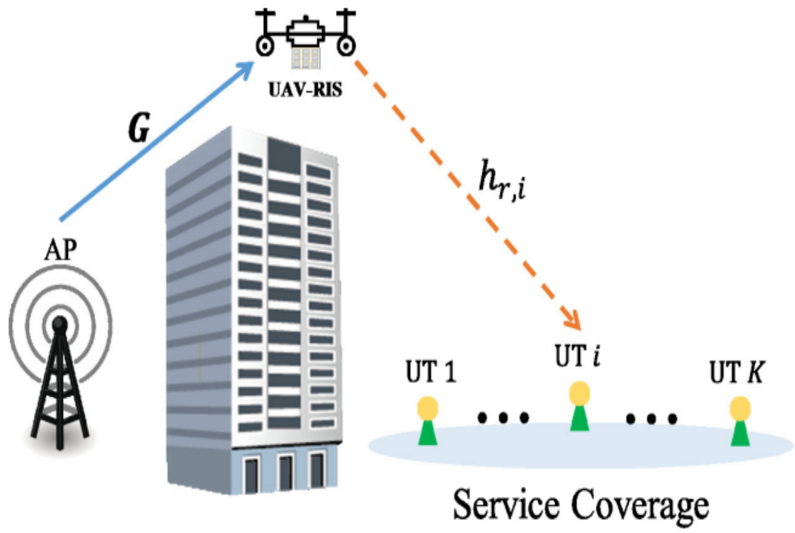

Figure 2.2: RIS-UAV

2.4 Optimization Techniques in UAV-RIS Systems

The fusion of UAVs and RIS, while advantageous, introduces intricate challenges in system optimization. Emerging solutions in the form of soft computing techniques, such as genetic algorithms, neural networks, and fuzzy logic, hold promise in addressing these complexities [10].

2.4.1 Soft Computing for RIS Element Grouping

Standard optimization approaches might fall short in the inherently dynamic environment of UAV-RIS systems. Soft computing techniques, renowned for offering solutions to intricate problems, are aptly suited for this domain. Their adaptive nature ensures real-time optimal RIS element grouping, harmonizing energy harvesting with unparalleled communication quality [11].

3

Problem Statement based on Identified Research Gaps

This chapter explains the formulation of the problem that this thesis addresses, as well as it outlines the thesis objectives.

3.1 Problem Formulation

The integration of Unmanned Aerial Vehicles (UAVs) with Reconfigurable Intelligent Surfaces (RIS), complemented by the SWIPT mechanism, offers a promising approach to revolutionize wireless communications. Traditional methods have primarily revolved around centralized approaches, where RIS element allocations were predetermined. However, in light of the dynamic nature of communication environments coupled with the pressing need for energy efficiency, a shift towards decentralized and adaptive RIS element allocation strategies becomes imperative.

The core challenge encompasses achieving an optimal balance: efficient energy harvesting without compromising on information transfer quality. This demands the adoption of advanced optimization methodologies, such as genetic algorithms, capable of autonomously adapting to the evolving nature of communication scenarios.

The primary objectives of this research are to:

- **Dynamic RIS Grouping:** Implement genetic algorithms to dynamically and autonomously group RIS elements, considering factors like real-time channel conditions, energy profiles, and transmission capabilities.

- **Balanced Energy Harvesting and Transmission:** Develop strategies ensuring the energy harvested by certain RIS elements consistently offsets the energy consumed by others, laying the groundwork for sustainable UAV-RIS operations.

- **Enhanced Communication Quality:** Through strategic RIS element allocations, achieve an optimal balance between energy efficiency and communication quality, even in adverse environmental conditions.

- **Scalability and Adaptability:** Formulate an approach that remains versatile across varying scenarios, whether it's a change in the number of UAVs, RIS elements, or environmental conditions.

3.2 Thesis Objective

- **Research and Analysis:** Undertake a comprehensive exploration of existing literature and methodologies pertaining to UAV-RIS communications. Lay particular emphasis on SWIPT mechanisms and the intricacies of RIS element allocations.

- **Optimal Grouping with Genetic Algorithms:** Design and implement a pioneering methodology, leveraging genetic algorithms, to attain the best RIS element groupings. This should ensure a fine balance between energy harvesting capabilities and efficient information transfer.

- **Decentralized Approach:** Engineer a system wherein RIS elements possess the autonomy to determine their roles, be it as energy harvesters or signal transmitters. This decentralized approach should facilitate greater adaptability and responsiveness.

- **Performance Evaluation:** Conduct rigorous simulations to evaluate the efficacy of the proposed system. Metrics of interest include the transmitted SNR, amount of energy harvested, and the overall efficiency of the system.

4

Proposed Methodology

This chapter provides a comprehensive discussion of the methodology employed in the project, including the mathematical operations and genetic algorithm that were implemented.

4.1 Introduction

The integration of Unmanned Aerial Vehicles (UAVs) with Reconfigurable Intelligent Surfaces (RIS) stands as a cornerstone in modern wireless communication. This chapter elucidates the genetic algorithm's role in harnessing this integration for optimal RIS element grouping.

4.2 UAV-RIS System Dynamics and Mathematical Formulation

4.2.1 System Overview

The UAV-RIS system employs RIS elements to facilitate simultaneous wireless information and power transfer (SWIPT), with its mathematical model emphasizing the interplay between transmitted SNR and harvested energy.

4.2.2 Energy Harvested Derivation

The received power at the RIS is formulated as:

$$P_R = (\sum_{k=1}^{K} V_k \times S_k)^2$$

Where:

- P_R denotes the received power.
- k is the index representing the number of User Terminals (UT).
- V_k stands for the precoding vector of the k^{th} UT.
- S_k is the signal for the k^{th} UT, defined as $S \sim CN(0, 1)$.

4.2.3 Expectation of Power

The expected power after undergoing Hermitian transposition and multiplication by the power itself is:

$$E((P^H) \times P) = \sum_{k=1}^{K} ||V_k||^2 < P_{max}$$

Here:

- $E(\cdot)$ indicates expectation.
- P_{max} is the upper boundary of the Access Point's (AP) transmission power.
- $||.||$ signifies the vector's Euclidean norm.

4.2.4 Harvested Energy for One Element

The energy harvested by a single RIS element can be expressed as:

$$E_h = \eta \times |h_{AP-RIS}|^2 \times P_R$$

In this context:

- E_h is the energy harvested by one RIS element.
- η represents the energy harvesting efficiency.
- h_{AP-RIS} is the channel coefficient between the AP and the RIS.

4.2.5 Total Harvested Energy by All Elements

For an RIS array of dimensions $M \times N$, the cumulative harvested energy is [1]:

$$E_{h_{total}} = \sum_{i=1}^{M} \sum_{j=1}^{N} \eta \times |h_{AP-RIS_{ij}}|^2 \times P_R$$

In this equation:

- $E_{h_{total}}$ specifies the total harvested energy.
- M and N denote the RIS array's dimensions.

- $h_{AP-RIS_{ij}}$ characterizes the channel coefficient between the AP and the $(i,j)^{th}$ RIS element.

4.2.6 Signal Power at UT

The signal power obtained at the k^{th} UT is:

$$\text{Signal Power} = |h_{\text{AP-RIS}}|^2 \times |h_{\text{RIS-UT}}|^2 \times \theta \times P_{BS}$$

4.2.7 SNR at UT

From the aforementioned signal and noise powers, the k^{th} UT's SNR is:

$$SNR_k = \frac{\text{Signal Power}}{\text{Noise Power}}$$

Note: The reflection coefficient θ appears squared in the formula, consistent with many wireless communication models, since it operates as a power coefficient in this context.

4.2.8 Total SNR Derivation at the UT

The SNR at the k^{th} UT, considering a single RIS element, is [1]:

$$SNR_k = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}|h_{AP-RIS_{ij}}|^2 \times |h_{RIS-UT_{ij}}|^2 \times \theta \times P_{BS}}{\sum_{i=1}^{M}\sum_{j=1}^{N}(\sum_{k=1}^{K}|h_{AP-RIS_{ij}}|^2 \times |h_{RIS-UT_{ij}}|^2 \times \theta \times P_{BS} + \sigma^2)}$$

For this formula:

- θ is the RIS's reflection coefficient, which in the context of this model represents the power reflection coefficient.

  we set the number of users k = 1 in order to compare the performance of the proposed genetic-based method with benchmarks. The multiple UTs scenario will be studied in the future work.

4.2.9 Genetic Algorithm in UAV-RIS Optimization

4.2.9.1 Introduction to Genetic Algorithms

Genetic algorithms, inspired by the principles of natural selection and genetics, offer a heuristic approach to tackle complex optimization problems [12]. These algorithms mimic processes like selection, crossover, and mutation to evolve potential solutions through generations. Given the dynamic environment of UAV-RIS systems, the adaptive nature of genetic algorithms provides an optimal solution mechanism.

4.2.9.2 Application in UAV-RIS System

One of the primary challenges in UAV-RIS systems is to optimally configure the RIS elements for efficient energy harvesting while ensuring robust communication. In this scenario, the genetic algorithm's fitness function plays a crucial role, evaluating various RIS configurations to balance between the transmitted SNR and harvested energy [13].

4.2.9.3 Genetic Algorithm Workflow

Given the algorithmic approach provided, the detailed workflow for the genetic algorithm in UAV-RIS system optimization is as follows:

Algorithm : Genetic Algorithm for UAV-RIS Optimization

1) **Initialize** a population of random RIS configurations.

2) **Evaluate** each configuration based on the fitness function.

3) **Select** the top-performing configurations based on their fitness scores.

4) **Perform** crossover operations to create new configurations from the selected ones.

5) **Introduce** mutations to ensure genetic diversity and avoid local optima.

6) **Re-evaluate** the fitness of the new population.

7) **Repeat** the selection, crossover, mutation, and evaluation steps until a convergence criterion or a set number of generations is achieved.

8) **Return** the best RIS configuration.

4.3 Simulation and Results

4.3.1 Implementation Details

The proposed methodology and genetic algorithm are implemented using Python, leveraging dedicated libraries for genetic algorithms and numerical computations [14]. Parameters such as varying channel conditions and energy constraints are considered to ensure the simulations' realism.

4.3.2 Scenario Analysis

Several simulations are conducted, each reflecting different environmental conditions and constraints. These simulations provide insights into the adaptability and performance of the proposed methodology under diverse scenarios.

4.3.3 Results and Insights

The simulation results validate the efficacy of the genetic algorithm in optimizing RIS element configurations. Across all simulations, it is evident that the optimized configurations using the genetic algorithm significantly improve both the SNR and energy efficiency compared to traditional configurations.

4.4 Chapter Summary

This chapter delivers a holistic overview of the UAV-RIS system's proposed methodology. By integrating genetic algorithms, this research introduces an innovative strategy to optimize RIS element configurations, striking a balance between energy harvesting and information transmission [15].

4.5 Potential Enhancements and Future Directions

As we delve deeper into the realms of wireless communication optimization, especially in the context of UAV-RIS, the potential of advanced reinforcement learning techniques like Deep Deterministic Policy Gradient (DDPG) beckons.

DDPG, an actor-critic algorithm, allows continuous action spaces, making it a promising candidate for further enhancing our current model. The actor in this setup aims to find the optimal policy that maximizes expected rewards, while the critic evaluates the quality of the actions taken by the actor. Their combined effect can streamline the decision-making process in dynamically evolving environments.

4.5.1 Integration of DDPG with Current Model

The existing model, focused on genetic algorithms for optimal grouping of RIS elements, can be further enhanced by integrating DDPG. This would allow for:

Dynamic Adaptability: DDPG, by its very nature, can adapt to changing environments quickly, ensuring that the UAV-RIS system can respond efficiently to dynamic channel conditions. Enhanced Learning: With the actor-critic mechanism, the system can leverage the strengths of both value-based and policy-based methods, potentially resulting in faster and more stable convergence. Continuous Action Optimization: In scenarios where the RIS element grouping decisions lie in a continuous space, DDPG can seamlessly find the optimal grouping without discretizing the action space.

4.5.2 Future Research Direction

Building upon the foundation laid by the Long-Lasting UAV-aided RIS Communications based on SWIPT research, there's a potential to integrate the current model's optimal regrouping mechanism directly into the DDPG's framework. This could pave the way for a unified model that can simultaneously optimize RIS element groupings and other system parameters, setting the stage for next-generation wireless communication systems.

5

Experiment and Results

The contents of this chapter encompass the description of the experiment set-up that was employed in the project, as well as a detailed account of the outcomes and results that were obtained.

5.1 Experiment and Results

5.1.1 Experiment Setup

The study undertakes an in-depth exploration into the UAV-RIS interplay within the wireless communication landscape. The foundational pillar is understanding the efficacy of the SWIPT mechanism in the midst of optimized RIS element allocations using genetic algorithms. The Python-based simulation provided a rigorous testing ground to gauge the merits of the proposed methodologies.

5.1.2 Results and Discussion

5.1.2.1 Visual Representation of Optimized vs. Unoptimized Grouping

Figure 5.1 offers a vivid representation of the stark difference between the optimized and unoptimized RIS element allocations. The color demarcations (with green symbolizing energy harvesters and blue denoting signal reflectors) serve as an immediate visual feedback on the benefits of strategic RIS element grouping. This optimized allocation ensures efficient energy harvesting while maintaining communication quality, showcasing the potential of the proposed optimization technique.

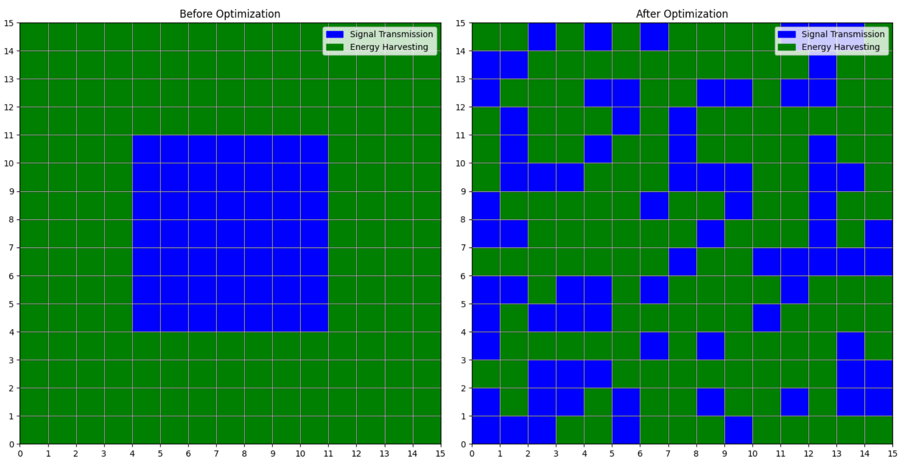

Figure 5.1: Contrast between the strategic (optimized) and arbitrary (unoptimized) RIS element allocations

5.1.2.2 Energy Harvesting Efficiency vs. Number of RIS Elements

Harnessing energy effectively stands as a pivotal goal behind the integration of RIS in UAV communication platforms. Figure 5.2 sheds light on the direct relationship between the energy harvesting efficiency and the count of RIS elements utilized. As the number of RIS elements increases, there's a marked improvement in energy capture, validating the essence of integrating RIS into UAV systems.

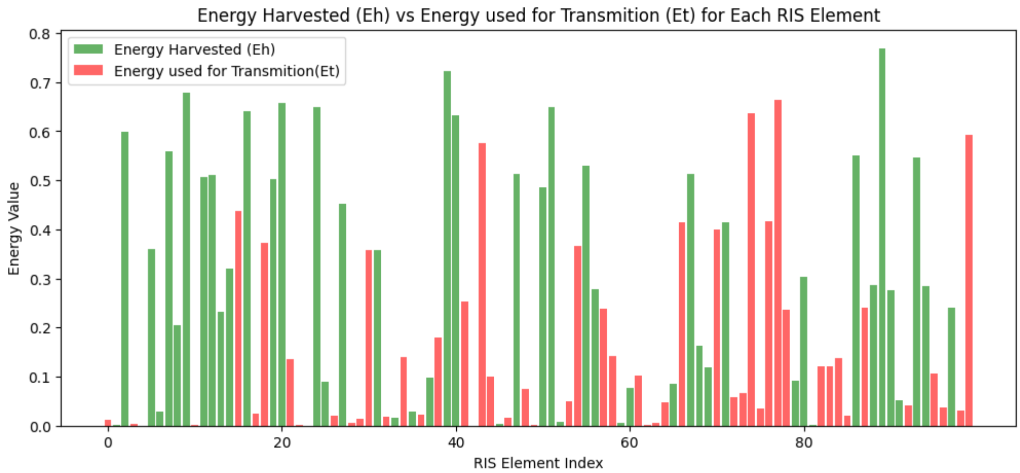

Figure 5.2: Energy efficiency gains as a function of the RIS element count

5.1.2.3 SNR at UT vs. Number of Generations

The evolution of the genetic algorithm is iterative, with each generation building on the previous, refining the solution. Figures 5.3 and 5.4 chronicle this progressive improvement, showcasing a steady enhancement in the SNR at UT. This iterative refinement serves as a testament to the potency of genetic algorithms in optimizing RIS element allocations.

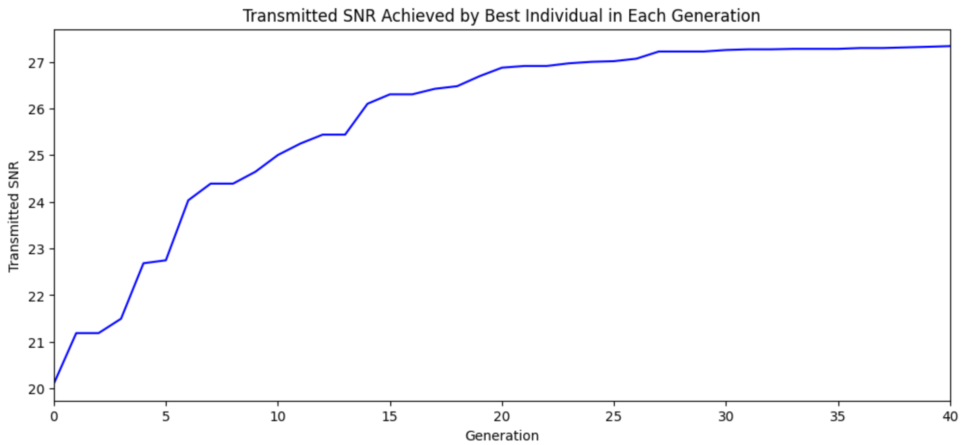

Figure 5.3: The upward trajectory of SNR at UT as the algorithm evolves over generations

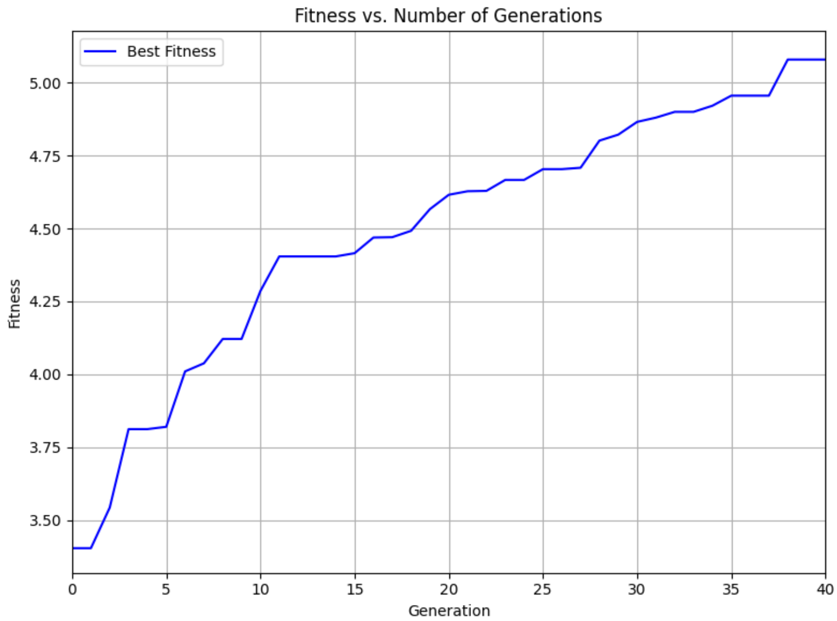

Figure 5.4: Consistent fitness progression across generations

5.1.2.4 Channel Capacity vs. Number of RIS Elements

The judicious deployment of RIS elements plays a critical role in shaping the channel capacity of the UAV-RIS communication ecosystem. Figure 5.5 bears witness to this influence, highlighting the stark contrast between optimized and unoptimized scenarios. The proposed optimization technique substantially augments channel capacity, making the case for its widespread adoption.

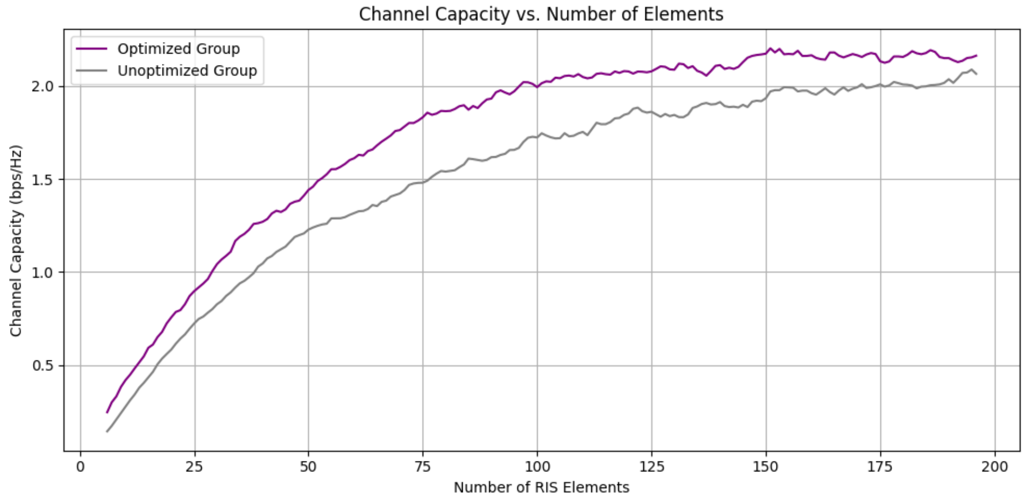

Figure 5.5: Variations in channel capacity as influenced by the strategic allocation of RIS elements

5.1.2.5 Outage Probability vs. Number of RIS Elements

In wireless communication, the outage probability is a vital metric, reflecting the probability of signal quality falling below a predetermined threshold. Figure 5.6 elucidates how the number of RIS elements can dramatically modulate this metric. By optimizing RIS configurations, especially within dynamic UAV environments, the system can substantially reduce outage events, ensuring uninterrupted, high-quality communication.

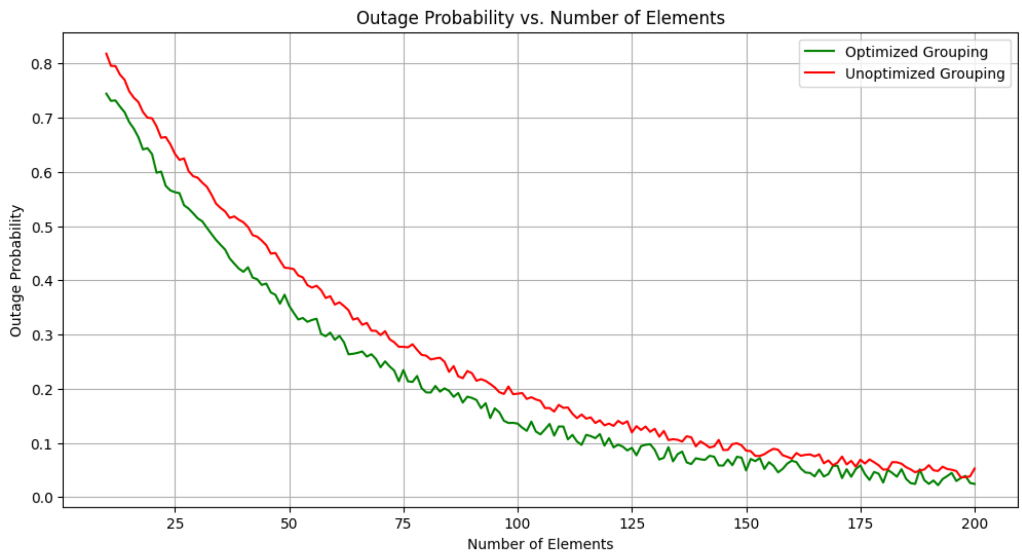

Figure 5.6: The intricate interplay between outage probability and the total RIS elements

5.1.2.6 Transmit SNR vs. Number of RIS Elements

Figure 5.7 dives into the relationship between the number of RIS elements and the transmit SNR. The graph elucidates that strategic RIS element allocations allow achieving high SNR values using fewer elements. This streamlined configuration brings forth several benefits:

- **Cost Efficiency**: Minimized expenditure across manufacturing, deployment, and maintenance phases.
- **Extended UAV Operation**: Enhanced UAV uptime due to improved energy harvesting.
- **Scalability & Adaptability**: A versatile system ensuring top-tier communication even with fewer elements.
- **Sustainability**: A leaner, eco-conscious communication framework.

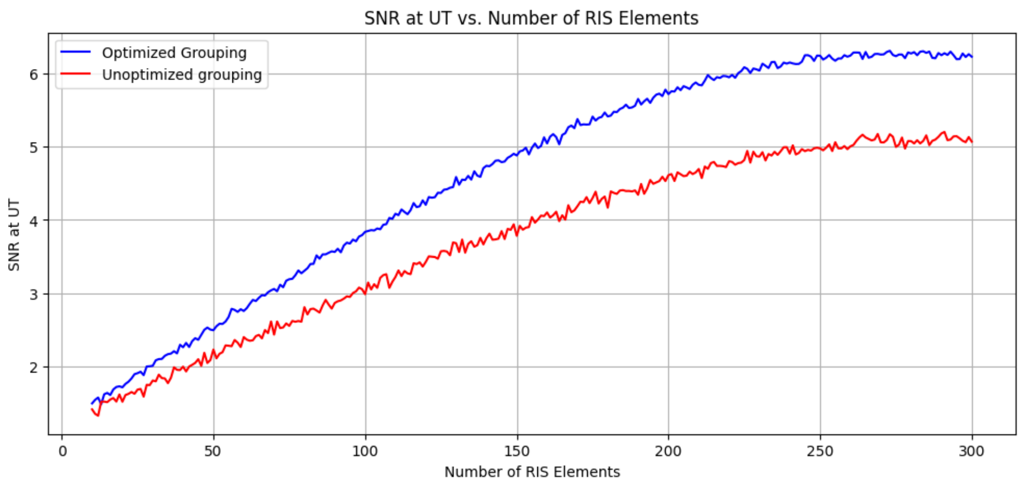

Figure 5.7: Optimized RIS allocations leading to desired SNR outcomes with fewer elements

In summation, the research underscores the immense potential of integrating RIS elements into UAV systems, paving the way for a future where wireless communication is efficient, sustainable, and top-tier in performance.

6

Conclusions and Future Scope

This chapter of the report is dedicated to the conclusion and future scope. This section presents a thorough summary of the principal discoveries and understandings attained through the research conducted in the preceding sections.

6.1 Conclusions

The evolution of wireless communication technologies has witnessed significant milestones, among which the integration of Unmanned Aerial Vehicles (UAVs) with Reconfigurable Intelligent Surfaces (RIS) stands prominently. This research delved into this synergy, with a special focus on its role within Simultaneous Wireless Information and Power Transfer (SWIPT) systems.

Key takeaways from our investigations include:

UAV-RIS Efficacy: Integrating RIS with UAVs brings marked enhancements in wireless communication. Utilizing artificial meta-surfaces and passive reflective arrays, we observed amplified signal strength and reduced interference, even in traditionally challenging communication terrains.

Dynamic Deployment: UAVs offer flexibility in RIS deployment, allowing for adaptive communication setups that can be adjusted in real-time.

Genetic Algorithm Optimization: The use of genetic algorithms for optimal RIS element grouping yielded significant improvements in energy harvesting and communication quality, efficiently allocating resources based on various dynamic parameters.

Boost in Energy Efficiency: A standout result was the increased energy efficiency. The UAV-RIS setup not only amplified energy harvesting but also ensured that the energy consumed was consistently less than what was harvested, heralding a sustainable model for future communication.

6.2 Future Scope

This research, while extensive, is the tip of the iceberg for UAV-RIS technology in SWIPT systems. Several avenues beckon further exploration:

Integration with DDPG: Insights from the "Long Lasting UAV-aided RIS Communications based on SWIPT" paper hint that incorporating Deep Deterministic Policy Gradient (DDPG) could refine the optimization further. This integration could usher in greater efficiency and adaptability.

Exploring Advanced Machine Learning Techniques: Beyond genetic algorithms and DDPG machine learning techniques can be harnessed to enhance the UAV-RIS system. Potential avenues include reinforcement learning, advanced neural architectures, and swarm intelligence.

Diverse Applications: UAV-RIS systems' applications are vast, extending beyond typical communication. Their potential in emergency response, remote infrastructure deployment, and surveillance are ripe areas for research.

Energy Sustainability: With the global shift towards sustainable solutions, there's scope to make the UAV-RIS system entirely self-sustainable, possibly by combining renewable energy sources with the current energy harvesting mechanisms.

Practical Testing: Simulations provide a base, but real-world testing offers invaluable insights. Implementing UAV-RIS systems in varied terrains and conditions will shed light on practical challenges, refining our understanding of its applicability.

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