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Department of Electrical and Electronics Engineering

UNIFIED OUTAGE PERFORMANCE ANALYSIS OF ANTENNA SELECTION TECHNIQUES IN UAV-ASSISTED NETWORKS

Master Thesis

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Supervisor

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DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Ibrahim Khaleel AL QARAHGHLI

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The thesis study of Ibrahim Khaleel titled as Unified Outage Performance Analysis of Antenna Selection Techniques in UAV-Assisted Networks has been accepted as MASTER THESIS in the department of Electrical and Electronics Engineering by out jury.

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SUMMARY

In this thesis, we thoroughly examine the performance and efficacy of diverse Antenna Selection (AS) strategies within a relay communication system facilitated by Unmanned Aerial Vehicles (UAVs). In this setup, UAVs serve as airborne relays, establishing and sustaining communication links between source and destination nodes. Our investigation encompasses a range of AS techniques, including transmit antenna selection/maximal ratio combining (TAS/MRC), joint transmit and receive antenna selection (JTRAS), and maximum ratio transmission/receive antenna selection (MRT/RAS). To comprehensively evaluate their performance in UAV relay networks, we conduct a unified analysis of outage probability (OP). Initially, we derive a closed-form expression for OP, specifically tailored for Nakagami-m fading channels. Additionally, we present an asymptotic expression to unveil the array and diversity gains, providing deeper insights into system performance. To corroborate our theoretical findings, we employ Monte Carlo simulations, ensuring the validation and reliability of our results.

Key Words: Antenna selection (AS), joint transmit and receive antenna selection (JTRAS), maximum ratio transmission/receive antenna selection (MRT/RAS), transmit antenna selection/maximal ratio combining (TAS/MRC), signal to noise ratio (SNR), outage probability (OP), unmanned aerial vehicle (UAV).

ÖZET

Bu tezde, İnsansız Hava Araçları (İHA'lar) tarafından kolaylaştırılan bir röle iletişim sisteminde çeşitli Anten Seçimi (AS) stratejilerinin performansını ve etkinliğini ayrıntılı olarak inceliyoruz. Bu kurulumda, İHA'lar hava röleleri olarak hizmet eder ve kaynak ve hedef düğümler arasında iletişim bağlantılarını kurar ve sürdürür. İncelememiz, iletişim sistemlerindeki performanslarını kapsayan bir dizi AS tekniğini içerir, bunlar arasında verici anten seçimi/maksimum oranlı birleştirme (TAS/MRC), ortak verici ve alıcı anten seçimi (JTRAS) ve maksimum oran iletimi/alıcı anten seçimi (MRT/RAS) bulunmaktadır. İHA rölesi ağlarında performanslarını kapsamlı olarak değerlendirmek için, kesilme olasılığının (OP) birleşik bir analizini gerçekleştiriyoruz. İlk olarak, Nakagami-m zayıflama kanalları için özel olarak uyarlanmış bir OP için kapalı form ifadesi türetiyoruz. Ayrıca, dizi ve çeşitlilik kazanımlarını açığa çıkarmak için bir asimptotik ifade sunuyoruz, sistem performansı hakkında daha derin bir anlayış sağlıyoruz. Teorik bulgularımızı doğrulamak için Monte Carlo simülasyonları kullanarak sonuçlarımızın doğruluğunu ve güvenilirliğini sağlıyoruz.

Anahtar kelimeler: Anten seçimi (AS), ortak verici ve alıcı anten seçimi (JTRAS), maksimum oran iletimi/alıcı anten seçimi (MRT/RAS), verici anten seçimi/maksimum oranlı birleştirme (TAS/MRC), sinyal-gürültü oranı (SNR), kesilme olasılığı (OP), insansız hava aracı (İHA).

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ABBREDIVATIONS

5G	**:**	Fifth Generation
AS	**:**	Antenna Selection
BER	**:**	Bit Error Rate
dB	**:**	Decibel
GHz	**:**	Gigahertz
IoT	**:**	Internet of Things
JTRAS	**:**	Joint Transmit and Receive Antenna Selection
LOS	**:**	Line of Sight
LTE	**:**	Long-Term Evolution
MHz	**:**	Megahertz
MRC	**:**	Maximal Ratio Combining
MRT	**:**	Maximum Ratio Transmission
NLOS	**:**	Non-Line of Sight
OP	**:**	Outage Probability
QoS	**:**	Quality of Service
RAS	**:**	Receive Antenna Selection
RF	**:**	Radio Frequency
SIMO	**:**	Single Input Multiple Output
SNR	**:**	Signal to Noise Ratio
SNR	**:**	Signal-to-Noise Ratio
TAS	**:**	Transmit Antenna Selection
UAV	**:**	Unmanned Aerial Vehicle

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INTRODUCTION

Integrating Internet of Vehicles (IoV) communication into sixth-generation (6G) mobile networks has significantly facilitated big data transmission through IoV communication systems. It has paved the way for innovative 6G IoV applications, such as automatic driving, intent sharing, and interactive gaming. Current IoV communication systems face challenges in meeting transmission requirements, such as ultra-reliable and low-latency communication. The advent of 6G IoV has enabled broader signal coverage compared to 5G IoV, exceeding ground IoV capabilities. Additionally, given the escalating complexity of modern vehicular networks, characterized by diverse vehicles and dynamic topology, aerial platforms have gained prominence within the 6G IoV communication landscape. Unmanned aerial vehicles (UAVs) are extensively embraced to bolster wireless communications in IoV communication systems (Zeng et al., 2016c).

There are numerous applications for UAVs, including load capacity, flight altitude, and endurance time enhancements. Moreover, UAV communications are rapidly advancing and garnering significant attention from industry and academia. Contrary to traditional ground communications, UAV com- munications have several clear advantages. First, UAVs are easy to deploy and highly flexible. Equipped with communication devices, UAVs facilitate the swift establishment of communication links. The capability to regulate the UAV's altitude at any given moment enables adaptable coverage and network capacity, aligning with mission requirements, especially for time-sensitive missions. Due to their compact size, lightweight nature, and ease of transportation, UAVs can be flexibly deployed or redeployed to meet evolving business needs, reducing network costs and energy consumption. Secondly, UAV communications are not hindered by challenging terrain. Traditional wireless communications are frequently impeded by obstacles like tall buildings or high mountains, significantly deteriorating communication quality based on the height of the base station or ground devices. In contrast, UAVs possess aerial superiority, enabling them to circumvent obstacles and establish dependable communication links. Lastly, UAV equipment demonstrates robust applicability and high-quality information transmission. UAV platforms can

readily upgrade communication equipment to enhance communication quality. In most cases, operating at low altitudes, UAVs enable the establishment of short-distance line-of-sight (LOS) communication links with ground users, significantly reducing path loss. These advantages position UAV communications as a promising technology for future wireless communication networks (Akhtar & Saeed, 2023; Salih et al., 2023; Shakhatreh et al., 2019).

In the literature, UAVs, functioning as flying communication stations, present three typical scenarios to assist and enhance communications: UAV-aided relaying, UAV-aided ubiquitous coverage, and UAV-aided information dissemination and data collection. Notably, leveraging UAVs as aerial relays holds promise as an attractive solution to enhance the capabilities of existing wireless communications. Compared to traditional single-hop communications, relay transmission technology significantly extends the system's coverage, effectively miti- gates channel loss during information delivery, and bolsters the reliability of wireless communications. Given the advantages of UAVs, they emerge as promising candidates to serve as flexible flying relays, facilitating efficient data transmissions(B. Li et al., 2021).

Multiple-input multiple-output (MIMO) technology has the potential to enhance the effectiveness of wireless systems concerning capacity and error rates. Antenna diversity methods are employed either at the transmission or reception ends of MIMO systems in various manners, mitigating the adverse impacts of fading channels in wireless communication. Despite yielding superior data capacity and enhancing overall system performance, these antenna diversity approaches contribute to heightened hardware complexity and increased power usage due to the presence of multiple radio frequency (RF) chains of antennas. However, antenna selection (AS) techniques, such as transmit antenna selection/maximal ratio combining (TAS/MRC) (Aldababsa, 2023b), joint Transmit and receive antenna selection (JTRAS) (Aldababsa & Basar, 2022), and maximum ratio transmission/receive antenna selection (MRT/RAS) (Aldababsa, 2023a), offer a solution to mitigate the mentioned limitations while retaining the benefits of multi-antenna systems with a reduced count of RF chains (Aldababsa et al., 2022; Demirkol et al., 2022).

The usage and benefits of Outage Probability in UAV-Assisted Networks are:

- Performance Assessment: Outage probability measures the reliability of communication links, crucial for applications like emergency response and military operations where consistent connectivity is vital.
- Network Planning and Optimization: Understanding outage probability helps in optimizing UAV placement and movement to enhance coverage, signal strength, and reduce interference.
- Resource Allocation: It aids in optimal allocation of bandwidth and power among UAVs, ensuring balanced and reliable coverage, especially in resource-limited scenarios.
- Design of Robust Communication Protocols: Insights from outage probability guide the development of adaptive protocols, including modulation, coding, and power control, to maintain performance under varying conditions.
- Enhancing Quality of Service (QoS): Low outage probability ensures high QoS for applications such as real-time video streaming and telemedicine by providing stable communication links.
- Emergency and Disaster Management: Reliable communication in emergencies is ensured by minimizing outage probability, enhancing coordination and information dissemination among responders.
- Scalability and Flexibility: Outage probability helps UAV-assisted networks adapt to dynamic environments and changing topologies, ensuring performance stability in temporary or rapidly evolving deployments.

Thesis Motivations:

Most of the aforementioned studies on UAV communication networks have primarily focused on UAV-trajectory optimization UAV-energy efficiency maximization, and UAV-performance analysis. Notably, a common aspect among these studies is the examination of UAV-assisted networks utilizing a single antenna. However, it is well established that employing multiple antennas has the potential to

enhance the efficacy of wireless systems significantly. Consequently, this serves as a compelling impetus for our investigation into UAV-assisted networks employing multi-antenna configurations.

Thesis Contributions:

The distinct contributions of this thesis are delineated as follows.

- The performance of various AS techniques are investigated, namely TAS/MRC, JTRAS, and MRT/RAS, within a UAV-assisted relay communication system. In this system, a UAV serves as a flying relay, facilitating establishing and maintaining communication links between source and destination nodes.
- We present a unified analysis of OP performance concerning the AS techniques employed in UAV relay networks. This analysis incorporates a unified assessment framework for the OP, consolidating insights into the reliability aspects of the system.
- Initially, closed-form expressions characterizing the OP under Nakagami-m fading channels are derived. This analytical foundation provides the essential basis for understanding reliability performance in challenging fading channel conditions.
- Furthermore, we conduct an asymptotic analysis in the regime of high signal-to-noise ratio (SNR), offering profound insights into the system's performance. By deriving a closed-form expression for the asymptotic OP, we gain substantial information regarding the array and diversity gains achieved by the system.
- Additionally, Monte Carlo simulations are conducted to validate and corroborate the theoretical findings. The simulation outcomes closely align with the derived theoretical expressions, affirming our analytical framework's accuracy. Notably, these results underscore a significant improvement in OP performance with an augmentation in transmit and receive antennas across all nodes. Moreover, heightened performance is

observed as channel conditions improve. Specifically, the TAS/MRC and MRT/RAS schemes exhibit superior performance compared to JTRAS, albeit at the cost of increased computational complexity. Notably, the OP performance deteriorates with an increase in the UAV's distance from the ground nodes.

Thesis Outline:

Here's a brief outline of the thesis based on its chapters:

Chapter 1 Background: This section introduces UAV-assisted networks, their significance, and the concept of MIMO (Multiple Input Multiple Output) systems. It discusses the various antenna selection techniques in MIMO systems and presents the challenges and potential of UAV communications in 6G networks.

Chapter 2 Literature review: This chapter provides a detailed analysis of UAV network systems, including their configurations and communication technologies. It delves into channel models for UAV communications, discussing both line-of-sight and non-line-of-sight scenarios.

Chapter 3 Analysis of Antenna Selection Techniques: This part of the thesis presents a unified analysis of various antenna selection techniques, their theoretical validation, and simulation results.

Chapter 4 Asymptotic Analysis and Performance Evaluation: This chapter focuses on the long-term performance characteristics of antenna selection techniques and their implications for UAV relay system design.

Chapter 5 Comparative Analysis and Discussion: The thesis concludes with a comparative analysis of different antenna selection techniques, discussing their practical applications and future perspectives.

CHAPTER ONE

BACKGROUND

1.1. Introduction to UAV-Assisted Networks

UAVs, also known as Drones, have gone a long way since their humble origins as military tools. They have proved extremely valuable in civilian enterprises. At the beginning of the 20th century, UAV communications were introduced for the first time. These communications were primarily utilised by the military for the purpose of conducting observation and surveillance. New civilian applications for UAVs have emerged as a result of technology advancements that have led to an increase in the capabilities of these vehicles over time (Nex et al., 2022).

It is essential for the future of UAV communications that advancements be made in navigational systems, digital communication, and autonomous control. In the beginning, UAVs were nothing more than simple planes that were operated remotely and had a specific military function. However, now that more powerful navigation and communication technology has been developed, UAVs are able to do more difficult tasks on their own (Bayomi et al., 2023).

UAVs have a wide range of applications in the field of communication networks. These are becoming more popular as a means of providing temporary network coverage in regions that have been ravaged by natural disasters and either lack traditional communication infrastructure or have suffered serious damage to it. It is essential to have the ability to rapidly deploy UAVs in order to ensure efficient communication when it comes to rescue and relief missions (Al-Khafajiy et al., 2020).

However, UAVs have the capability to extend network coverage to remote areas where it would be impossible or expensive to establish traditional infrastructure(Aoueileyine et al., 2023; Hemmati et al., 2023). They are able to perform the job of mobile base stations by linking places that are not currently being serviced and making it easier to access healthcare, education, and emergency response services.

UAVs in urban settings improve the quality of service and reduce congestion, both of which contribute to the enhancement of current communication networks. This

is especially true during times of high demand or when there are large-scale public events. They are able to dynamically alter their placements based on the concentration of the user, which allows them to maximise network performance and deliver a seamless user experience (Yazid et al., 2021).

The new Internet of Things network is equally dependent on UAVs. Because of their capacity to collect and transmit data in real time from Internet of Things (IoT) sensors, they have made it feasible for a variety of applications to be implemented. Some examples of these applications include smart city management, environmental monitoring, and precision agriculture. Due to their mobility and versatility, UAVs are ideal for the collecting of data from locations that are inaccessible. This, in turn, assists in the process of decision-making (Messaoudi et al., 2023).

The inclusion of UAVs into communication networks has proven successful in fostering research in a variety of domains, including interference management, signal processing, and network optimisation. The creation of effective algorithms and protocols to manage the ever-changing nature of UAV-assisted networks is an important area of study that is being conducted (Rovira-Sugranes et al., 2022). This will ensure that communication is both trustworthy and of the highest available quality.

The history of UAV communications reveals, in conclusion, the change of these communications from specialist military technology to adaptable assets in civilian communication networks. UAVs are a game-changer in the wireless communications business because of the agile, inexpensive, and speedy deployment possibilities that they bring. UAV-assisted networks are expected to have even more applications and capacities in the future, becoming an essential component of the communication systems that are in use now as a result of the continual advancements in technology.

1.2. Fundamentals of MIMO Systems

Multiple inputs MIMO technology is a groundbreaking approach in wireless communication that significantly enhances the efficiency and reliability of data transmission. The transmitter and receiver of a multiple-input multiple-output (MIMO) system utilise a large number of antennas. This configuration enables the transmission and reception of many data streams simultaneously using a single radio channel. The utilisation of data stream parallelism significantly enhances the

performance of the communication system without requiring more bandwidth (Gesbert et al., 2003).

Multipath propagation, a fundamental characteristic of multiple-antenna systems, refers to the phenomenon where transmitted signals reach the receiving antenna over diverse paths. In traditional single-antenna systems, signal fading and diminished data quality are prevalent consequences of this phenomena. MIMO technology capitalises on several paths to increase data transmission, thereby turning this challenge into a favourable circumstance. The antennas of the receiver have the ability to decode many signal paths, allowing for the transfer of a greater amount of data using the same frequency spectrum (Kiani et al., 2023).

Regarding MIMO technology, it is crucial to consider several significant approaches. Spatial multiplexing is a technique that allows many data streams to be sent simultaneously over a single communication channel utilising multiple antenna. Beamforming is a technique that enhances the quality of a signal received by focusing the transmission power in a certain direction, hence increasing the signal strength and reducing interference (Mutlu & Kabalcı, 2022).

MIMO systems employ diversity techniques, such as spatial diversity, to enhance transmission reliability and combat signal fading. This is achieved by utilising many antennas. The occurrence of simultaneous deep fading in all signals is reduced when several copies of the signal are transmitted over various routes (Kelechi et al., n.d.).

The use of MIMO technology in networks that include UAVs offers significant benefits. It enhances the communication of UAVs, enabling the reliable transfer of substantial volumes of data, even under challenging conditions. Video streaming, surveillance, and large-scale data collection are a few instances of applications that depend on the instantaneous flow of data.

Prior to using multiple-input multiple-output (MIMO) technology, UAV communication systems need to thoroughly assess factors such as antenna placement, design, and signal processing algorithms, due to their constrained power and compact size (Chandhar & Larsson, n.d.). MIMO is essential for the advancement of UAV-

assisted communication networks since it can potentially enhance network efficiency and performance.

1.3. Antenna Selection Techniques in MIMO Systems

The selection of antennas is crucial in multiple-input multiple-output (MIMO) systems to optimise performance while minimising complexity and cost (Kumar et al., 2023). By considering criteria like channel conditions and signal intensity, these techniques choose the most suitable antennas from a larger array for the purpose of transmission and reception (Marinello et al., 2020). Choosing the appropriate antenna (Khalid et al., 2020) facilitates the task of striking a balance between system performance and practical constraints, such as power use and hardware restrictions. By employing intelligent antenna selection, these solutions enhance the efficiency and reliability of MIMO systems across many applications, such as UAV-assisted communications. This leads to significant improvements in data throughput and signal quality (Khan et al., 2022).

1.4. Challenges and Limitations in Current Research

When doing research into communication networks that are helped by UAVs, researchers are aware of the fact that there are significant limitations and impediments in the current state of the art. constraints imposed by technology, such as limited battery life, payload constraints, and the robustness of communication networks in a variety of scenarios, are among the important concerns that require more research. Airspace control and regulatory considerations, as well as the complexity of connecting with established communication systems, are other factors that contribute to the challenges that occur. Further, it is abundantly obvious that research into autonomous flight control, the effective distribution of resources, and the development of new data processing techniques is of critical importance. The growing concerns regarding privacy and security, particularly in civilian settings, bring to light the necessity of continuous innovation in UAV applications that involve specialists from a variety of fields.

1.5. Potential of UAV Communications in 6G Networks

The introduction of UAVs into 6G networks is a significant advance in communication technology that has the potential to have far-reaching and revolutionary repercussions. UAVs are expected to play a crucial position in the ecosystem of the planned 6G network. This is because they will provide unique solutions to the existing issues of network coverage and reliability, particularly in areas that are not covered or that are located in remote areas. As a consequence of their possible usage as aerial base stations or relays, 6G networks will be able to make use of their improved capacity and coverage area. For the purpose of paving the way for cutting-edge network capabilities such as three-dimensional coverage and very dependable low-latency communications, autonomous vehicles and sophisticated Internet of Things (IoT) applications will rely on this integration. Furthermore, because of their adaptability in dynamically adjusting network design, UAVs are ideal for facilitating communications between massive machines, which is an essential component of new generation (6G) networks. Through the facilitation of dispersed network operations and edge computing, this feature has the potential to enhance the responsiveness and efficiency of 6G services. By using UAVs in 6G networks, which usher in a new age of highly powerful, flexible, and adaptive network designs, wireless communications are always evolving. This is just one example of how wireless communications are constantly improving.

CHAPTER TWO

LITERATURE REVIEW

The second chapter is structured to offer a comprehensive analysis of the technology components that underpin UAV-assisted networks in addition to literature review of the study. This chapter will provide a comprehensive analysis of the UAV network system, encompassing its configurations, features, and communication technologies. The subsequent discourse will delve into channel models, elucidating the various channels and their impact on signal transmission, including line-of-sight and non-line-of-sight channels. Before discussing antenna selection methods, this thorough research establishes the foundation for understanding the complexities and capabilities of UAV communication systems.

2.1. Literature on UAV-Assisted Communication Networks

The literature has extensive study on UAV-assisted communication networks, encompassing several aspects including their development, applications, and challenges. The extensive body of research illuminates the ways in which UAVs enhance communication performance, reliability, and network coverage.

The feasibility of incorporating UAVs into terrestrial networks has been extensively investigated (Gu & Zhang, 2023; Jeelani & Gheisari, 2021; Z. Zhang & Zhu, 2023). To optimise the extent and connectivity, especially in regions without infrastructure, these studies often emphasise the tactical positioning and mobility of UAVs (Cabreira et al., 2019; X. Li & Savkin, 2021). Many individuals are contemplating the potential of UAVs to assist in disaster relief and rescue operations by rapidly establishing communication networks in regions that have been severely affected (Erdelj & Natalizio, 2016a; Saif et al., 2023).

Another prominent subject of discussion is the independent aerial navigation of UAVs utilising communication networks. The research in this field has mostly concentrated on instructing UAVs to employ sophisticated algorithms and artificial intelligence (AI) to enhance their navigation, network administration, coverage, and data transfer (Mohd Daud et al., 2022).

Another crucial field of research pertains to the distinctive challenges encountered in UAV-assisted networks, particularly the imperative to establish and sustain reliable communication links in dynamically evolving environments. Studies have tackled issues such as signal interference, low battery life, and fluctuating channel conditions by offering innovative solutions to these difficulties (Lahmeri et al., 2021).

Another field of research is exploring the potential of UAVs for long-range communication, which might contribute to bridging the digital divide by providing internet connectivity in remote or otherwise inaccessible locations (Gupta et al., n.d.; Rolly et al., 2022). Given the extensive accessibility to the internet, the significance of this aspect of UAV communication cannot be overstated.

Ultimately, there exists a substantial and diverse corpus of study on the use of UAVs to enhance communication networks. This research encompasses a wide range of topics, including particular technological challenges and their corresponding solutions, as well as broader implications of deploying UAVs to enhance global connectivity. This comprehensive compilation of research offers a solid foundation for present and future advancements in the field.

2.2. Overview of UAV-Assisted Network Systems

Both academia and industry have shown a keen interest in utilising UAVs for enhancing communications and networking (F. Cheng et al., 2018; Zeng et al., 2016a; N. Zhao et al., 2018). In their study, Zeng et al. enhanced the efficiency of UAV-enabled mobile relaying by concurrently optimising the transmit power and relay trajectory. Zhao et al. proposed a safe transmission approach in hyperdense networks utilising UAVs and caching (J. Zhao et al., 2018). Zhao et al. (Wu, Zeng, et al., 2018) proposed a blind beam tracking approach for UAV-satellite communications, which involves using a large-scale antenna array on the UAV. Wu et al. (D. Yang et al., 2018) achieved remarkable results by simultaneously adjusting the trajectory, transmit power, and scheduling of the UAV, in order to optimise the minimum throughput of ground devices. Yang et al. (Ahmed et al., 2016) investigated the energy trade-off associated with data collection from the ground to the UAV by employing two different trajectory optimisation techniques. In accordance with the findings presented in reference (Xu et al., 2018), Ahmed et al. employed empirical data to analyse and

define the channel models for UAV communications. In their study, Xu et al. introduced a novel wireless power transmission system that employed UAVs (Wu, Xu, et al., 2018). This system utilised an UAV equipped energy transmitter to provide wireless energy to several ground-based receivers. Cheng et al. proposed an optimisation method for UAV flight paths in order to reduce traffic congestion for base stations located at the edges of adjoining cells (F. Cheng et al., 2018). Wu et al.(Y. Chen et al., 2018) established the capacity zone of a UAV-enabled two-user broadcast channel by optimising both the trajectory and the transmit power or rate concurrently. Chen et al. (Menouar et al., 2017) investigated two prevalent ways for relaying data among several UAVs. One approach included a single multihop connection, while the other method utilised multiple dual-hop links. The researchers identified the optimal hovering sites for each method. Menouar et al. (Erdelj & Natalizio, 2016b) discussed the potential and challenges of using UAVs for intelligent transportation systems and demonstrated their practical applications.

2.2.1. UAV-Assisted Network Systems

Despite the extensive literature on UAV communications, there have been few studies on the use of UAV help in disaster response networks (Christy et al., 2017; Erdelj & Natalizio, 2016b; Mase & Okada, 2015). Erdelj and Natalizio presented the application of UAV networks in disaster management in their publication (Erdelj & Natalizio, 2016b) and examined several unresolved inquiries pertaining to this domain. Mase and Okada conducted a research investigating the use of UAVs for message transmission in the context of major disasters (Mase & Okada, 2015). Christy et al. (Christy et al., 2017) designed a UAV flight route to enhance device-to-device (D2D) communication in times of calamities.

UAVs have rapidly gained popularity in several industries because to their versatility, cost-effectiveness, mobility, and ease of use. The domains included are precision agriculture, civil infrastructure inspection, security, surveillance, real-time monitoring, communication coverage, remote sensing, search and rescue, product delivery, and others. Many commercial UAVs now on the market are equipped with WiFi connection, enabling remote access. Conversely, if you need a connection that can span a wide area, WiFi may not be sufficient for your Line of Sight (LoS) communication requirements. The use of current Long Term Evolution (LTE)

networks for UAVs has seen a significant increase in activity in recent years, with several field trials and research projects underway (Burke, n.d.; Dong et al., 2020).

Extensive research has been conducted on integrating UAVs with cellular communication systems to guarantee reliable exchange of mission-related data and secure management of UAV operations. This is particularly relevant with the emergence of 5G technology and the potential future implementation of 6G technology (Zeng et al., 2016b). UAVs with distinct objectives are a possible new user of cellular networks. The integration of GPS and cellular signals enhances the effectiveness of lawful UAV monitoring and management, while also improving the reliability of UAV navigation. This is achievable due to the sophisticated cellular technology and the widespread availability of cellular networks. If specialist UAVs were utilised as relays, aerial base stations (BSs), or access points (APs) to help terrestrial wireless communications from above, a new paradigm known as UAV-assisted communications might potentially arise (Mao et al., 2017).

There has been a recent increase in the usage of resource-intensive applications on our user equipments (UEs), such as smartphones and other portable devices. This is due to the rapid growth in popularity of categories such as autonomous driving, online gaming, health monitoring, and virtual reality (VR). However, this contradicts the prevailing trend of portable UEs' small size and long battery life. Fortunately, there is a remedy available known as mobile edge computing (MEC) (P. Zhang et al., 2022). This relocates the 3C resources communication, computation, and caching to the outer edges of the network. In the future, it is expected that networks would have the capability to efficiently and reliably manage on-demand hotspot zones and temporary activities, while also adapting to a highly dynamic and diversified environment. The previous MEC system is rigid and may incur significant installation expenses due to its fixed infrastructure (N. Cheng et al., 2018). Given the adaptability of UAVs, it might be advantageous to consider the installation of edge servers on board these aircraft (Erdelj et al., 2017).

In future wireless networks, the rising availability of UAVs will eliminate the limitation of mobile users being restricted to terrestrial mobile stations. Refer to Figure 2.1 for a compilation of various applications of wireless networks for UAVs, such as disaster relief through UAV swarm networks (Hu et al., 2021), vehicle-to-everything

(V2X) communications (Lin et al., 2018), smart city development with UAV assistance, traffic offloading using hotspots, and Internet of Things (IoT) networks aided by UAVs. UAVs will prompt a change in the architecture of wireless networks, leading to the adoption of a three-dimensional structure that incorporates both ground-based and air-borne network nodes. This will make aerial-ground networks more flexible and versatile compared to the current static ground-based communications networks.

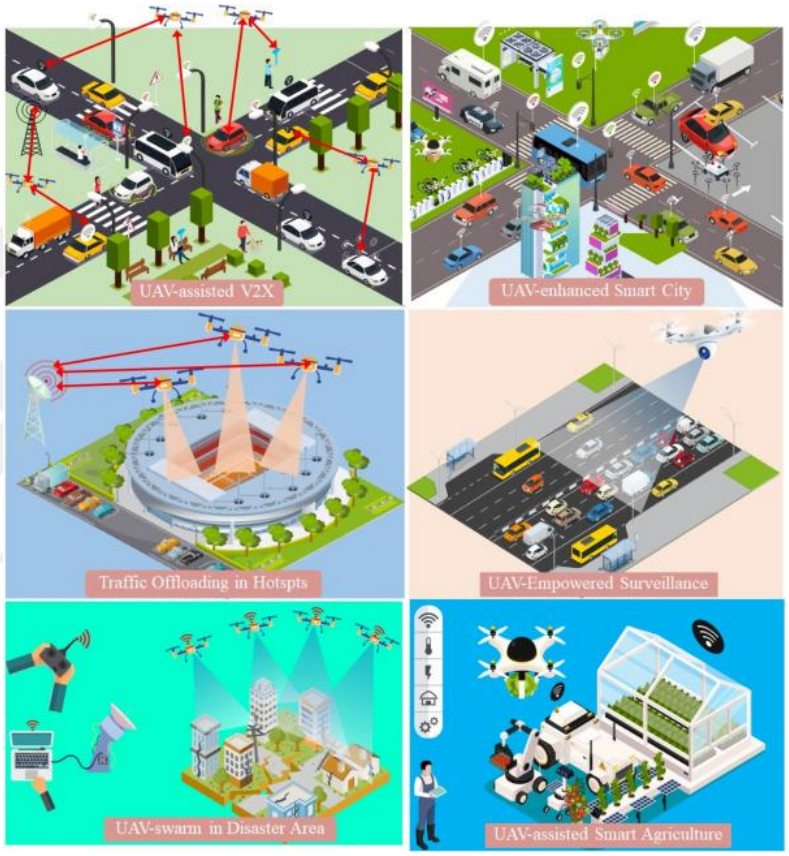

Figure 1. Applications of UAVs in wireless networks (Gu & Zhang, 2023)

Performance metrics are intricately linked to the design and implementation of UAV-enabled wireless networks. Here are few often utilised metrics: The highest throughput/capacity ratio is the primary requirement for achieving a successful data rate over a communication connection. The investigation of relay channel capacity is a thriving subject, and it is a crucial factor for optimising spectrum efficiency. Energy efficiency (EE) refers to the ratio of the total data bits transmitted to user end devices (UEs) by a UAV during its flight, divided by the total energy consumed for propulsion

by the UAV. Due to the inherent limitations of UAVs' energy supply, it is difficult to accurately assess the optimal utilisation of onboard energy by the system enabled by UAVs. Furthermore, the outage probability (OP) of a wireless system is a vital metric for assessing its performance. An important measure for evaluating communication capacity in slow-fading relaying channels is the probability that the current transmission rate exceeds the capacity of the current channel (OP). (4) To enhance communication performance, UAV-enabled systems must consider the fairness issue raised by nodes with diverse capacity. This encompasses the implementation of flexible communications that can adjust to changing conditions and the development of the flight path for the UAV. To optimise the minimum average user rate and ensure fairness, resources are reduced for users with higher channel gain due to their shorter distance to the UAV and higher data rate. These resources are then redistributed to users with lower channel gain. The packet loss rate quantifies the average number of packets that are not successfully sent within a single transmission period.

2.2.2. The roles of UAVs networks

Delivering top-notch services in densely populated areas with temporary high network traffic, like during the Olympic Games or the NBA Finals, is both crucial and challenging due to the risk of network congestion and prolonged service latency caused by the growing number of connected devices. It is important to consider that it is neither practicable or efficient to install a significant number of base stations in a small area or for temporary events. Here, a flying base station (BS), also known as a UAV-borne BS or access point, presents a promising opportunity to enhance network capacity. The utilisation of UAV-carried Base Stations (BS) and Access Points (AP) has the capacity to enhance network coverage in locations where land-based BSs are incapable of delivering service, such as rural regions or areas impacted by natural calamities. This is due to their uncomplicated deployment and flexible mobility (Qadir et al., 2021; Zeng et al., 2016c). In addition, UAVs are capable of efficiently performing massive multi-input multi-output (MIMO), 3D network MIMO, and mmWave communications. This is primarily due to the elevated position of the flying base stations (BSs), which allows for clear differentiation of ground users (GUEs) at various altitudes and elevation angles in relation to the UAV (Zeng et al., 2016c). Beamforming provides effective signal transmission in both the horizontal and vertical

directions due to the line-of-sight paths of communication between UAVs and the ground.

Figure 2 depicts the three primary roles of the UAV-assisted wireless network. Specifically, UAVs (UAVs) with significant autonomy in terms of their mobility and data gathering capabilities assist terrestrial networks in transmitting data, distributing information, and transferring power. UAVs may gather large amounts of data from various locations in a city and transmit it to centralised cloud units for analysis using big data techniques. By combining UAVs with sensors, data may be efficiently and precisely gathered, even in challenging or remote locations. Similarly, UAVs can enhance land-based networks by facilitating the dissemination of data and improving connectivity. This is possible due to their portable nature and Line of Sight (LoS) capabilities. When the performance of device-to-device (D2D) communication is limited due to variables such as a short communication range and potential interference, UAVs can efficiently disseminate information by intelligently broadcasting shared files to devices on the ground. Utilising mobile drones introduces new opportunities for diversifying transmission, hence enhancing the reliability and connectivity of D2D, ad hoc, and V2V networks. Furthermore, the integration of UAVs into WSNs helps mitigate the challenges arising from the constrained computational capabilities, storage capacity, and energy consumption of sensor nodes. UAV-enabled WSNs can enhance network performance and prolong the lifetime of nodes by allowing sensors to make intermittent connections instead of maintaining a continuous connection with data centres. In order to enhance the longevity of low-power rechargeable sensors/devices, it is imperative to incorporate wireless power transfer (WPT) technology into the UAV. The use of line-of-sight (LoS) links may greatly improve the energy transfer efficiency of the UAV -enabled wireless power transfer (WPT) system, where the UAV serves as a mobile energy transmitter.

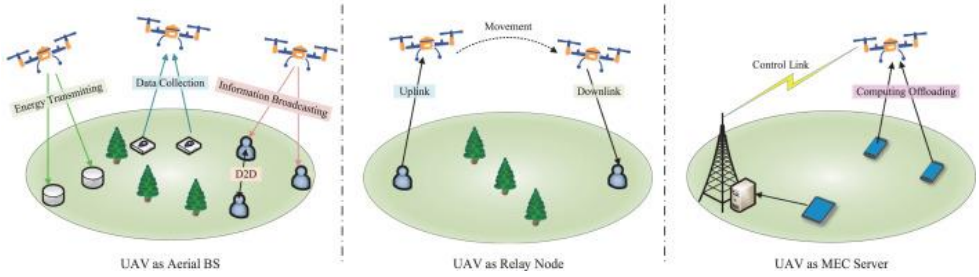

Figure 2. The roles of UAVs (Gu & Zhang, 2023)

UAVs assume the function as relays because to their high computing power, facilitating the transmission of data between various networks or user equipment (UEs). Mobile relays in the form of UAVs offer several further advantages as compared to traditional terrestrial relays. UAV relays are ideal for last-minute or emergency circumstances because to their affordability and simplicity of deployment. Moreover, UAVs can enhance network performance by strategically relocating themselves to enable Line of Sight (LoS) air-ground communications, owing to their exceptional mobility. Specifically, the establishment of airborne UAV relays may be achieved by employing multi-hop relay transmission technology.

The computation-constrained and energy-efficient User Equipments (UEs) of the Internet of Things (IoT) encounter a significant obstacle in the next 5G era, since the extensive interconnections in communication networks will inevitably generate vast volumes of data. An effective approach to address these issues is Mobile Edge Computing (MEC), which has the capability to alleviate the computational burden on User Equipments (UEs) (S. Liu et al., 2019). Each Base Station (BS) or Access Point (AP) installed on a Mobile Edge Computing (MEC) platform is often equipped with its own computing and caching capabilities. These resources can be configured in a way that allows User Equipment (UE) to delegate some or all of their tasks to the BS or AP. In data-intensive settings where only mobile edge computing (MEC)-mounted base stations (BSs) are accessible, there is still a possibility of underutilised or wasted resources, despite the various and potentially changing resource needs of user equipment (UE). This is especially accurate in situations when there is a high volume of traffic caused by social gatherings or activities. Moreover, several user equipments (UEs) located in mountainous or otherwise hard-to-reach areas suffer from a lack of both infrastructure coverage and reliable mobile edge computing (MEC) service. Fortunately, these problems may be reduced by deploying UAVs that are equipped with mobile edge computing (MEC) servers to assist certain base stations (BSs) or provide coverage for faraway user equipment (UE) (W. Chen et al., 2019).

UAVs can improve communication services by acting as flying base stations (BSs) and relays. They can also assist by taking over compute jobs from ground units (GUEs) or neighbouring UAVs, functioning as airborne mobile edge computing (MEC) servers. This configuration establishes an integrated mobile network that

combines air and ground capabilities. Before UAVs may be used for targeted networking objectives, there are several technological challenges that need to be overcome, notwithstanding their promise. When developing a UAV for use as an aerial base station (BS), it is crucial to consider factors such as job allocation, optimal three-dimensional deployment, optimising flight endurance and trajectory, and organising the network. Nevertheless, the UAV-relaying system faces several potential challenges, including the mode of operation, handover management, channel modelling, relaying protocols, optimisation of UAV placement, trajectory, velocity, and acceleration, improvement of security and reliability, and resource allocation. Furthermore, the edge computing situation has several significant issues, such as: handling interference, distributing workloads, determining computation offloading, user association and scheduling, and managing multi-access and low-latency control, as well as 3D localization.

2.3. MIMO System Models in UAV Networks

2.3.1. Basic Architecture and Principles

A vital component of UAV networks is the use of multiple antennas at both the transmitter and receiving ends. MIMO systems, which stand for multiple input multiple output, are responsible for this. Through the use of this configuration, wireless communication channels are rendered more dependable and competent. The use of several antennas in order to take advantage of spatial diversity makes it possible to transmit many data streams simultaneously, which is the fundamental concept. Because of this, the throughput is increased without the requirement of additional bandwidth or transmit power having to be added (Chandhar & Larsson, 2019).

If MIMO systems are integrated with UAV networks, there are a number of benefits and drawbacks associated with this integration. Because UAVs are able to roam about, the communication environment is always moving, and the relative placements of the antennas are also fluctuating. MIMO systems are required to be flexible as a result of the fact that channel characteristics might vary dramatically in a short amount of time. The ability to fly at a high altitude provides UAVs with a line-of-sight advantage, which makes them more resistant to fading and multipath than terrestrial wireless systems. In situations like these, adaptive transmission techniques

and robust algorithms for real-time channel estimates are required in order to make effective use of MIMO(Alshaibani et al., 2022a).

2.3.2. Channel Modeling and Capacity Analysis

Channel modelling in UAV networks that make use of multiple input multiple output (MIMO) systems is a key component for improving communication protocols and predicting system performance. A unique propagation environment is created by elements such as the movement of UAVs, their altitude, and barriers, and the channel model has to take these elements into mind. The choice of model, which can be either Rician or Rayleigh fading, is determined by the line-of-sight situations because of the circumstances. Temperature and humidity are two examples of atmospheric elements that should be taken into consideration because of the possible implications that they might have on the transmission of communication signals (Khuwaja et al., 2018).

What capacity analysis of MIMO systems in UAV networks is all about is determining the greatest feasible data rate that can be achieved under specific channel conditions. Throughput optimisation of antenna design and transmission algorithms is something that can be accomplished with the help of this study. The number of antennas, the signal-to-noise ratio, and the fading characteristics of the channel are some of the elements that might have an impact on the capacity of a multiple-input multiple-output (MIMO) system. It is possible to employ other techniques, such as spatial multiplexing and beamforming, in order to achieve an even greater capacity gain. To develop efficient UAV communication systems that are able to serve applications that need high data rates, it is necessary to have a comprehensive grasp of these aspects.

2.3.3. Adaptive Techniques and Future Challenges

As a result of the inherent dynamic nature of aerial communication channels, adaptive techniques are required for MIMO systems in UAV networks. A number of approaches, including adaptive modulation and coding, beamforming, and antenna selection, are extremely important. Through the use of these techniques, the system has the potential to enhance its performance and maintain the dependability of the connection by modifying its settings in real time in accordance with the channel conditions. One example is adaptive beamforming, which enhances signal quality by

directing the transmission power towards the receiver. This is especially useful for long-distance communications, where improved signal quality is very important.

Integration with existing and upcoming wireless technologies, interference management, and scalability are some of the challenges that MIMO systems for UAV networks will need to surmount in the future. As the number of UAVs in a network increases, the difficulty of managing interference between a large number of UAVs also increases. Additionally, it is essential to find solutions to the technological problems that occur when combining MIMO systems with next-generation wireless technologies such as 5G and maybe even more advanced technologies. In the event that researchers in this subject are successful in tackling the challenges that are now being faced, future UAV communication systems will be more advanced, efficient, and reliable (Bliss & Govindasamy, 2011).

2.4. Channel Models for UAV Communications

2.4.1. Line-of-Sight (LoS) Propagation Models

Communication systems for UAVs are primarily dependent online-of-Sight (LoS) propagation models. This is due to the fact that UAVs frequently fly at heights that allow for straightforward channels that are free of obstructions. A straight line of sight between the two nodes is the focal point of these models, as is frequently the case with UAV communications, particularly in areas with a lower population density or in rural areas. Typically, LoS models make the assumption of minimal signal attenuation and fading in order to ease their investigation of signal strength and quality levels (Altaf Khuwaja et al., 2018).

The reliability of LoS models is significantly influenced by the environment as well as the height of the UAV. It is possible that the efficiency of LoS transmission might be reduced in highly populated places or on terrains that are complicated by the presence of buildings and other natural impediments. The altitude of the UAV is another significant issue to consider. Although flying at higher altitudes increases the possibility of maintaining a line-of-sight connection, it also poses challenges, such as being more susceptible to changes in the weather and perhaps imposing legal constraints on the maximum height at which UAVs can operate.

The distinction between lines of sight (LoS) and non-line-of-sight (NLOS) propagation is depicted in Figure 3, which is an illustration of UAV communication channels. Within the context of this line-of-sight (LoS) scenario, the UAV sends signals directly to the ground base station (PDB) using a Gaussian channel model (shown on the left). Within the context of the NLoS scenario represented on the right side of the picture, which makes use of a Rayleigh channel model, the blockage of the signal pathway results in multipath propagation and signal fading.

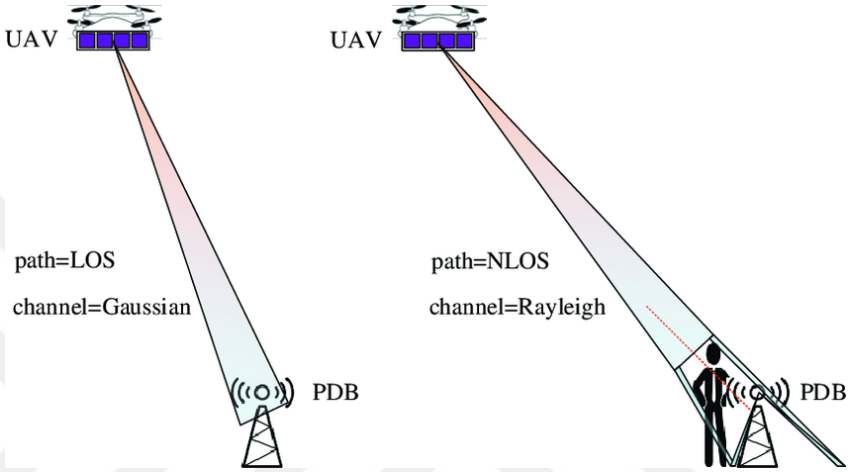

Figure 3. Line-of-sight (LOS) and non-line-of-sight (NLOS) scenes (Z. Zhang et al., 2020)

2.4.2. Non-Line-of-Sight (NLoS) and Multipath Models

In the context of dealing with complex and urban environments, where direct paths between the transmitter and receiver are frequently impeded, Non-Line-of-Sight (NLoS) and multipath models become extremely important. When dealing with NLoS situations, it is necessary to conduct a more comprehensive analysis that takes into account many paths that have different delays and attenuations. This is due to the fact that the signal experiences reflections, diffractions, and scattering on its journey to the receiver. Multipath propagation is a phenomenon that manifests itself when many reflected and scattered signals reach the receiver. Other symptoms of multipath propagation include signal fading and interference (Seow & Tan, 2008).

Complex algorithms, such as adaptive equalisation techniques and sophisticated error correction codes, are required for these models in order to mitigate the effects of signal fading and interference. Since the movement of the UAV has the potential to

significantly alter the propagation characteristics, the true challenge is in accurately predicting how signals will behave in environments that are constantly shifting. In spite of the fact that NLoS and multipath models are computationally expensive owing to their complexity, they are essential for urban UAV applications that demand reliable communication.

2.4.3. Hybrid and Emerging Models

The purpose of utilising hybrid models in UAV communications is to construct a framework that is more adaptable and dependable by combining the most advantageous aspects of both the LoS and NLoS/multipath methods. These models give a more realistic image of the UAV communication channel at various locations because they take into account the influence of multipath propagation, the possibility of LoS conditions, and the impact of NLoS. There is continuing research into hybrid models; the purpose of these models is to enhance the forecast of channel behaviour by including factors such as the speed of UAVs, urban density, and altitude.

Innovative technologies and methods, like machine learning and artificial intelligence, are being included into new UAV communications models in order to investigate how to dynamically predict and respond to challenging channel situations. Attempting to assess enormous amounts of data from a variety of sources, such as environmental sensors and real-time UAV operational characteristics, these systems have as their primary objective the process of continuously updating and refining the channel model. In the future, communication systems for UAVs stand to gain a great deal from this intelligent and adaptive approach. This is because the ability to anticipate and react to rapidly shifting conditions will be essential to the maintenance of strong and effective communication partnerships (Al-Gburi et al., 2022).

Figure 4 provides a comprehensive illustration of a communication network for UAVs that makes use of hybrid channel types. An UAV is seen in the image maintaining a steady line-of-sight (LoS) connection with the base station on the ground. There is also a connection between a second UAV and a Non-Line-of-Sight (NLoS) connection, which is shown as a dashed line to illustrate how intricate urban signal reflection may be. The ability of a third UAV to transition between local area network (LoS) and non-local area network (NLoS) connections is made possible by an

adaptive antenna system. The cloud is a metaphor for the computer resources that are used in this hybrid urban-open-space environment. These computer resources make use of machine learning, which is symbolised by the neural network icon, in order to analyse and optimise communication signals.

Figure 4. Hybrid Channel Models for UAV Communications

2.5. Antenna Selection Mechanisms in MIMO-UAV Systems

2.5.1. Fundamentals of Antenna Selection

Multiple-input multiple-output (MIMO-UAV) systems are characterised by the fact that the selection of an antenna has a significant influence on the overall performance of the system. It involves picking a subset of antennas from a larger array in order to either maximise the capacity of the system or decrease the error rates among the antennas. In most cases, the selection criterion is constructed using the following foundational elements: channel conditions, antenna patterns, and system limits. In order to circumvent the limitations imposed by the payload and power of the UAV,

the major purpose is to make use of the spatial diversity that is offered by MIMO systems (J. Zhang et al., 2019).

Utilising switches or utilising a network are the two primary methods that may be utilised in order to select antennas. Despite the fact that switch-based selection has some limits, such as the speed and durability of the switches, it is a straightforward and cost-effective method for selecting antennas by utilising RF switches. Network-based selection, on the other hand, is more flexible and performance-oriented since it uses algorithms and signal processing methods to pick the most suitable collection of antennas. With the goal of ensuring reliable communication in UAV networks, both systems aim towards striking a compromise between efficiency and complexity.

A representation of the MIMO-UAV in its base station and relay configuration may be found in Figure 5. You can see a MIMO-UAV base station on the left side of the photo. This base station is providing coverage to ground users by making advantage of its field of view. It is possible for a MIMO-UAV relay, which is seen on the right, to improve its communication range through the utilisation of 3D beamforming. This enables the relay to maintain its connection with ground users located at a considerable distance, even when it is confronted with obstacles that are generated by the terrain itself. A demonstration of the versatility of the UAV is the fact that it can switch gears and move from delivering direct service to increasing network coverage in challenging terrain.

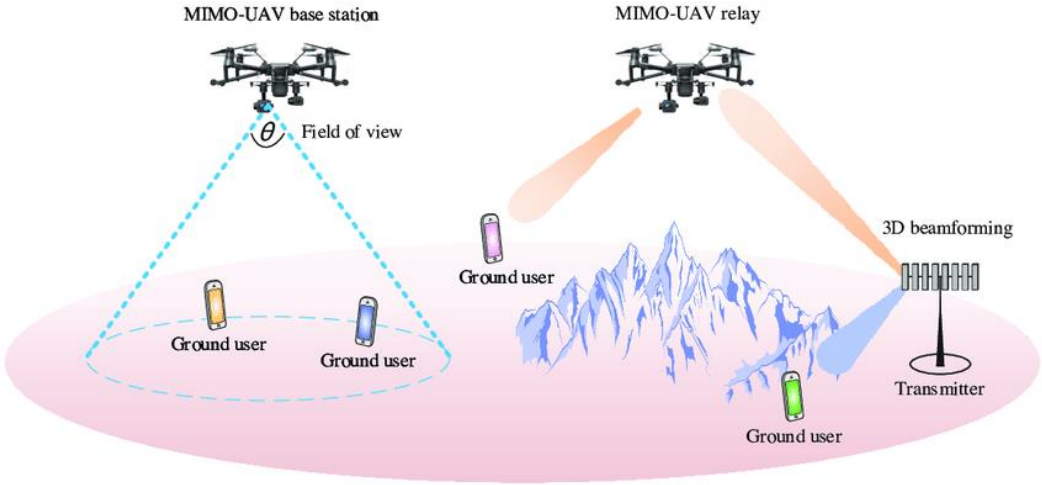

Figure 5. MIMO-UAV as Base Station and Relay (J. Zhang et al., 2019)

2.5.2. Optimization Algorithms for Selection

Antenna selection procedures are dependent on optimisation algorithms in order to either optimise the capacity of the system or limit the number of transmission errors. For instance, greedy algorithms select the ideal antenna on a recurrent basis based on a parameter, such as the channel gain or the signal-to-noise ratio. Despite the fact that they may not always yield the best results, these algorithms are simple to build and need a small amount of powerful computational resources. In contrast, more complicated algorithms, such as genetic algorithms or simulated annealing, are able to explore a larger field for a solution that is close to optimum, despite the fact that they need more computer resources.

It is difficult for these algorithms to adjust to the constantly shifting UAV channels because of the obstacle that they face. Feedback mechanisms and real-time channel estimations are required for these algorithms so that they may adjust their decisions in response to changing conditions. It is crucial that algorithms achieve a balance between complexity and performance. This is because UAVs have limited processing capacity, which makes it difficult for them to accomplish complicated tasks.

2.5.3. Impact of UAV Dynamics

An extensive range of UAV dynamics, including orientation, vibration, and movement, have an impact on the algorithms that are used to choose an antenna. Due to the growing mobility of UAVs, the approach for selecting antennas needs to be highly flexible and as rapid as possible. This is because the channel is continually shifting. There are a number of considerations that must be taken into consideration when selecting an antenna, including doppler shift and fluctuating multipath components. Alterations in signal quality might be brought about by these variables. In the event that algorithms are slow to react to these dynamics, it is possible that the result will be suboptimal antenna design and poor communication performance.

A robust antenna selection system that makes use of models that can predict the movement and orientation of UAVs is required in order to address these concerns. Using these models to make predictions about how the channel will evolve over time, the selection algorithm is able to determine in advance which antennas will deliver the

best results. To further increase the flexibility of the antenna selection process, it is possible to incorporate onboard sensor feedback in order to provide real-time data on the dynamics of the UAV (Alshaibani et al., 2022b).

Figure 6 illustrates a Dynamic Communication Network that includes UAVs. A satellite link, user equipment (UE) such as mobile phones, personal computers, and 3D mobile devices, and traditional cellular base stations (4G BS and 5G BS) are all shown in this network diagram as examples of handover (HO) scenarios that can take place between these three types of devices. The shown UAVs are capable of carrying out complex handover procedures, demonstrating their flexible purpose in ensuring that ground users have access to the network while they are on the go. The information presented in this picture illustrates the capability of the UAV to modify its mode of communication in response to the movement and varying positions of the network nodes.

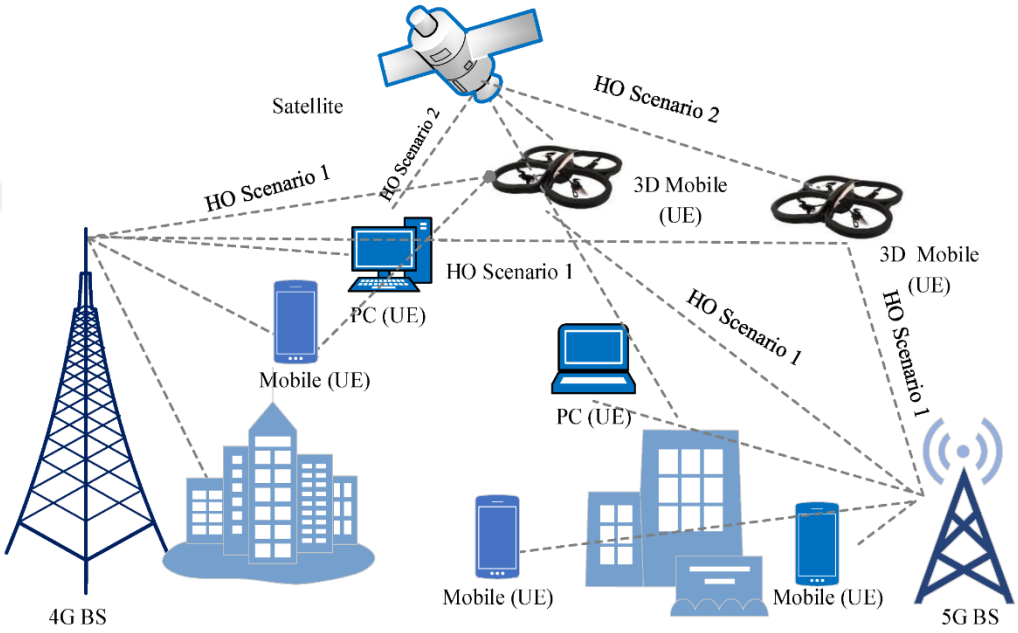

Figure 6. Dynamic Communication Network with UAV Involvement (Alshaibani et al., 2022b)

2.5.4. Practical Implementation and Challenges

When building MIMO-UAV systems, it is essential to take into account practical aspects such as the limits imposed by hardware, the amount of energy used, and the circumstances of the environment when implementing antenna selection strategies.

The development of lightweight antenna arrays that are capable of performing multiple-input multiple-output (MIMO) operations is a significant challenge that must be overcome in the technical realm. It is required to reduce the amount of energy that is expended by the associated gear and the antenna selection process in order to further increase the operating life of the UAV.

When attempting to include antenna selection techniques into various UAV components, there are also opportunities for problems to occur. In order to function properly, the navigation and flight control systems of the UAV must be able to communicate with one another without any interference. In order to ensure that your onboard electronics function in a dependable manner, you must minimise interference as much as possible. It is vital to overcome these issues in order to effectively deploy MIMO-UAV systems in a number of applications, including telecommunications and search and rescue operations. This is because the technology behind UAVs is advancing at a rapid pace.

2.6. Mathematical Modelling of Signal Propagation

2.6.1. Propagation Loss and Path Gain Models

When it comes to simulating signal propagation, there are two main components that are essential: route gain and propagation loss. When developing models of propagation loss, such as free-space path loss (FSPL), it is important to take into account the fact that the signal strength drops as a function of both the frequency and the distance. By examining these models, you might be able to get knowledge on the maximum speeds and power consumption of UAV communication systems. Path gain models, on the other hand, take into account the impact of antenna physical and geometric characteristics on signal intensity, in addition to gains resulting from antenna directivity .

In order to manage increasingly complex environments in which barriers and differences in topography have an effect on signal transmission, sophisticated mathematical methods such as log-normal shadowing and log-distance route loss models are utilised. When it comes to urban UAV deployments, one of the most significant challenges is signal loss over distance and over various obstructions. The

models integrate stochastic and deterministic components in order to accurately depict this challenging situation.

Propagation loss in a free space environment is represented by the Free-Space Path Loss (FSPL) formula:

$$\text{FSPL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \quad (1)$$

where d is the distance between the transmitter and receiver, f is the frequency of the transmitted signal, and c is the speed of light.

For more complex environments, the Log-Distance Path Loss Model is used:

$$\text{PL}(d) = \text{PL}(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (2)$$

Where PL (0) PL(d0) is the path loss at a reference distance d0, n is the path loss exponent indicating the rate at which the path loss increases with distance, and Xσ is a Gaussian random variable with zero mean and standard deviation σ, representing shadow fading.

2.6.2. Fading and Multipath Effects

It is not uncommon for UAV communications to have signal variations as a result of multipath fading. As a result of characteristics such as reflection, diffraction, or scattering, this phenomenon takes place when signals travel via a number of different channels before arriving at the desired destination. For the purpose of explaining signal behaviour in non-line-of-sight contexts, the Rayleigh fading model is crucial in UAV scenarios. On the other hand, the Rician fading model is vital for describing conditions that involve line-of-sight. Statistical approaches, as well as the description of changes in signal amplitude and phase shifts, are utilised when these models are subjected to mathematical treatment.

It is possible to use methods such as the Nakagami-m distribution or Clarke's model for Rayleigh fading in order to characterise the randomness of the received signal levels under a variety of UAV operational settings. This may be done in order to further refine these models. These models are helpful in simulating and forecasting how UAV communication systems would function in a variety of environmental

settings. They are important for the creation of communication protocols that are resilient and flexible.

Rayleigh fading, which is applicable when there is no line-of-sight path, can be modeled by a probability density function (PDF) of the received signal amplitude R:

$$f_R(r) = \frac{2r}{\Omega} e^{-\frac{r^2}{\Omega}} \quad (3)$$

where Ω is the mean power of the received signal.

In contrast, Rician fading, which occurs when there is a line-of-sight component, has the following PDF:

$$f_R(r) = \frac{2(K+1)r}{\Omega} e^{-K-\frac{(K+1)r^2}{\Omega}} I_0\left(2r\sqrt{\frac{K(K+1)}{\Omega}}\right) \quad (4)$$

where K is the Rician factor representing the ratio of direct path power to multipath power, and I0 is the modified Bessel function of the first kind and zero order.

2.6.3. Doppler Shift and UAV Mobility Models

The Doppler effect is a phenomenon that occurs when the frequency of a signal that is received fluctuates as a result of the relative speeds of UAVs. It is necessary to have mathematical models of the Doppler shift in order to develop frequency correction solutions for UAV communications. It is usual for these models to include a set of differential equations that establish a connection between the velocity vectors of the UAV and the frequency change rate.

In addition, UAV mobility models are utilised in order to anticipate the course of the UAV and the manner in which it will influence the transmission of certain signals. These models can be as simple as a collection of waypoints that are created at random, or they can be as complex as a collection of prediction algorithms that are selected depending on the characteristics of the mission, environmental conditions, and any obstacles that the UAV may meet. In order to ensure that communication is fluid and that handover strategies are successful in dynamic UAV networks, it is vital to have correct mobility models.

The Doppler shift due to UAV mobility is given by:

$$f_D = \frac{v}{c} f_c \cos(\theta) \quad (5)$$

where fD is the Doppler frequency shift, v is the velocity of the UAV relative to the receiver, c is the speed of light, fc is the carrier frequency, and θ is the angle of motion relative to the line-of-sight.

UAV mobility models often use equations of motion, for example, the Random Waypoint Model:

$$p(t+1) = p(t) + v(t)\Delta t + \frac{1}{2}a(t)\Delta t^2 \quad (6)$$

Where p(t) is the position vector, v(t) is the velocity vector, a(t) is the acceleration vector, and Δt is the time increment.

2.6.4. Channel State Information and Estimation Techniques

One of the most important factors in improving MIMO-UAV communication systems is having accurate channel state information (CSI). The calculation of CSI is accomplished via the use of mathematical models that make use of linear algebra and signal processing techniques that extract channel parameters from the received signal. Estimation methods such as blind estimation and pilot-based estimation are required in order to derive the channel matrix, which is comprised of the intricate channel coefficients that describe the propagation environment.

When attempting to frame estimation as an optimisation problem, one typical approach is to inquire about the means by which the difference between the actual and estimated channel states might be minimised. Iterative methods, such as the expectation-maximization algorithm or the least squares algorithm, are frequently utilised to find a solution to this issue. These methods are utilised in order to further enhance the CSI estimations. Techniques such as beamforming, spatial multiplexing, and power regulation are examples of adaptive transmission methods that are utilised in order to enhance the capacity and dependability of UAV communication networks. Statistical methods and mathematical models are utilised in the execution of these strategies.

Channel estimation can be expressed in terms of the channel matrix H and the received signal y:

$$y = Hx + n \quad (7)$$

where x is the transmitted signal vector, and n is the noise vector. Least squares estimation of H is commonly used:

$$\widehat{\mathrm{H}} = (\mathrm{X}^{H}\mathrm{X})^{-1}\mathrm{X}^{H}\mathrm{Y} \quad (8)$$

where X is the matrix of transmitted pilot symbols, Y is the matrix of received symbols, and H is the estimate of the channel matrix.

These formulas are central to the mathematical modeling of signal propagation in MIMO-UAV systems and provide the theoretical foundation for analyzing and simulating UAV communication links.

2.7. Antenna Selection Mechanisms in MIMO-UAV Systems

2.7.1. Antenna Selection Criteria

Antenna selection is an optimisation technique that takes into consideration a variety of criteria, including signal quality, capacity, and energy economy, when constructing a multi-input multiple-output (MIMO) UAV system. For the purpose of antenna selection, it is common practice to make use of the Shannon-Hartley theorem, which is a metric that takes into account channel capacity. It is possible to define the capacity C of a multi-input multiple-output (MIMO) channel with nt transmit antennas and nr receive antennas using the same equation (J. Yang et al., 2021). This is based on the assumption that the receiver has complete channel information.

$$C = \log_2 det\left(I_{n_r} + \frac{\rho}{n_t} HH^{H}\right) \quad (9)$$

In the above equation, the channel matrix is represented by the symbol H, the SNR is represented by the symbol ρ, and the identity matrix of r×n×n is represented by the symbol Inr. When considering the limited resources of the UAV , the objective is to optimise this capacity by picking the most appropriate subset of antennas.

When it comes to aerial selection, one of the criteria that might be considered is reducing the bit error rate (BER), which is especially important for applications that include UAVs and require extremely dependable data transmission. Through careful configuration of antennas, it is possible to obtain optimal signal quality and enhanced resistance to fading. The parameters, which must strike a balance between the two

opposing objectives of high data rates and trustworthy, error-free transmission, are often required to be determined by the task of the UAV (Ding et al., 2020).

2.7.2. Selection Algorithms

Managing antenna selection in MIMO systems may be accomplished using a variety of approaches, ranging from straightforward algorithms that rely on switches to more complex ones that make use of combinatorial optimisation. These approaches can be used to manage antenna selection. The popularity of greedy algorithms can be attributed to their ease of use and somewhat low processing costs. The following are the phases that an algorithm that is greedy will go through to explain it: In order to optimise the incremental capacity, it is necessary to begin with an empty set S, determine the additional capacity ΔCi that any antenna outside of S would provide, and then select the antenna that maximises this capacity. The process is repeated once it has been established how many antennas are required to meet the necessary requirements.

On the other hand, greedy algorithms might not always give the optimal configuration when applied to multifaceted channel setups. In spite of the fact that they need a significant amount of computer power, global optimisation techniques such as evolutionary algorithms and particle swarm optimisation are able to discover solutions that are close to optimum by examining the whole solution space. These methods are particularly effective in situations when the computational delay may be tolerated or where the UAV system is equipped with the processing capability to carry out complex computations (H. W. Chen & Liang, 2022).

2.7.3. Practical Constraints

The real-world limitations of UAV systems, such as their weight, size, power, and processing capabilities, have a significant impact on the antenna selection process. One area in which size and weight play a role in restricting the capabilities of UAVs is antenna capacity. It is essential to lessen the amount of power that the UAV consumes, which is influenced by each antenna, in order to keep it flying for as long as feasible. Therefore, while creating an ideal antenna selection mechanism, it is essential to take into consideration these restrictions that are related to the actual world. The following equation is an example of such an equation.

$$\max_{S\subseteq\{1,\ldots,N\},|S|=n_t} C(S) \quad \text{subject to } \sum_{i\in S} P_i \leq P_{max} \tag{10}$$

where N is the total number of antennas, C(S) is the channel capacity with subset S, Pi is the power consumption of the *i*th antenna, and maxP is the maximum power budget for the antennas.

As a result of these constraints, there is an immediate need for selection algorithms that are capable of dynamically adapting to the current states of the UAV system and the environment in which it operates. In order to make choices in real time that optimise the performance of the system while adhering to its operational limits, it is necessary to evaluate the present height of the UAV, both in terms of channel conditions and mission goals.

2.7.4. Adaptive Selection

It is essential for UAV systems to have adaptive antenna selection because of the constantly shifting nature of the operational environment of UAVs. Because of the relative mobility of the UAV and the base station, as well as the changing propagation circumstances, it is vital to have an antenna selection mechanism that is capable of adapting in real time. One method of describing this flexibility is by referring to a feedback loop that continuously monitors the channel state and makes adjustments to the antenna selection.

$$\mathrm{y}(t) = \mathrm{H}(t)\mathrm{x}(t) + \mathrm{n}(t) \tag{11}$$

where y(t) is the received signal vector, H(t) is the time-varying channel matrix, x(t) is the transmitted signal vector, and n(t) is the noise vector at time t. The antenna selection is then updated based on the estimated channel matrix.

In most cases, adaptive algorithms make use of a learning or estimation process in order to determine the ideal antenna design for succeeding time periods and to foresee the evolution of the channel. By predicting and responding to changes in the flight path of the UAV or the environment, these predictive models have the potential to significantly improve the responsiveness of the antenna selection process, therefore guaranteeing that communication performance is at its highest possible level.

2.8. Mathematical Modelling of Signal Propagation

2.8.1. Propagation Loss and Path Gain Models

Accurate modelling of signal propagation is essential for the development of trustworthy systems in UAV communications. If everything were to go according to plan, the Free-Space Path Loss (FSPL) model would be the initial bet for determining the degree to which a signal would deteriorate with increasing distance. A mathematical depiction of the FSPL is denoted by the equation (Ranjan et al., 2019).

$$\text{FSPL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \qquad (12)$$

where c represents the speed of light, f represents the frequency of the signal that is being broadcast, and d represents the distance that separates the recipient and the transmitter. Despite the fact that it is helpful as a starting point for additional study into signal attenuation, this model does not take into consideration contextual elements such as the weather or physical obstacles.

$$\text{PL}(d) = \text{PL}(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad (13)$$

on the other hand, in actual reality, more elaborate models that take into consideration the unpredictability of the environment are typically necessary. The Log-Distance Path Loss Model is an extension that takes environmental variables into consideration by adding the path loss exponent and shadow fading. This model is given by the equation.

Shadow fading is denoted by Xσ, which is a Gaussian random variable with a mean of zero and a standard deviation of σ. The known path loss at a reference distance d0 is denoted by PL(d0). n is the symbol that represents the path loss exponent. In order to accurately predict how effectively UAV communication lines will function in a variety of environments, these models are required (Ranjan et al., 2019).

2.8.2. Fading and Multipath Effects

The performance of wireless communication systems is susceptible to deterioration as a result of fading and multipath. It is common practice to assume that Rayleigh fading will occur in circumstances in which the transmitter and receiver are

not in a straight line of sight (NLoS). When a Rayleigh fading channel is used, the probability density function (PDF) is used to determine the amplitude R of the signal that is received for that channel (Ranjan et al., 2019).

$$f_R(r) = \frac{2r}{\Omega} e^{-\frac{r^2}{\Omega}} \quad (14)$$

where Ω is the average power received. This model helps in designing systems that are resilient to such fading conditions, which are common in UAV operations, especially at lower altitudes with dense obstacles.

In contrast, Rician fading is used when there is a line-of-sight (LoS) component in addition to the scattered paths. The PDF for the received signal amplitude

R under Rician fading is:

$$f_R(r) = \frac{2(K+1)r}{\Omega} e^{-K-\frac{(K+1)r^2}{\Omega}} I_0\left(2r\sqrt{\frac{K(K+1)}{\Omega}}\right) \quad (15)$$

where K is the Rician K-factor representing the power ratio between the LoS path and the scattered paths, and I0 is the zeroth-order modified Bessel function of the first kind. These models are fundamental in simulating and understanding the impact of multipath on UAV communication systems.

2.8.3. Doppler Shift and UAV Mobility Models

A shift in the frequency of the signal that has been received is brought about by the Doppler effect, which is brought about by the fast mobility of UAVs. The Doppler shift is a phenomenon that is especially visible in UAV communications due to the very high speeds involved. Equation provides this phenomenon.

$$f_D = \frac{v}{c} f_c \cos(\theta) \quad (16)$$

In this equation, the symbol fD represents the Doppler frequency shift, v represents the relative velocity of the UAV to the receiver, c represents the speed of light, fc represents the carrier frequency, and θ represents the angle of motion in regard to the line-of-sight. In order to design frequency compensation algorithms that ensure coherent demodulation at the receiver, it is crucial to precisely describe the Doppler shift. This is because the Doppler shift is a frequency transition.

Mobility models for UAVs are utilised in order to estimate the route and how it will impact the transmission of signals. When considering three-dimensional movement patterns, these models may become rather intricate; nonetheless, they often make use of kinematic equations that take into account the velocity and acceleration of the UAV . Accurate mobility modelling is essential for both predictive signal processing and the linking of UAVs to networks.

2.8.4. Channel State Information and Estimation Techniques

Channel State Information (CSI) is an essential component for MIMO systems, since it allows for the optimisation of data throughput and the adaptive distribution of resources. In order to calculate the CSI at the receiving end, the linear model that is presented below can be utilised.

$$y = Hx + n \tag{17}$$

where y is the received signal vector, H is the channel matrix, x is the transmitted signal vector, and n is the noise vector. The least squares estimation of the channel matrix H is given by:

$$\hat{H} = (X^H X)^{-1} X^H Y \tag{18}$$

In this equation, X represents the matrix of pilot symbols that were transmitted, and Y represents the matrix of symbols that were received. In MIMO-UAV systems, the effectiveness of power control algorithms, beamforming, and space-time coding is contingent upon the accuracy of the CSI estimation.

For the purpose of providing a comprehensive summary of the mathematical modelling that is involved in signal propagation for UAV communication systems, each of these subsections would include detailed explanations and examples of the equations that are provided.

2.9. Performance Metrics and Evaluation Criteria

2.9.1. Capacity and Throughput

When it comes to determining how effective MIMO-UAV communication systems are, capacity and throughput are two of the most important criteria to consider. It is standard practice to use bits per second per hertz (bps/Hz) as a unit of measurement

for capacity. This unit of measurement shows the theoretical maximum data rate that can be carried across a communication channel without losing effectiveness (Z. Liu et al., 2023). The Shannon-Hartley theorem is responsible for determining the equation, which is applicable to a MIMO system that was equipped with complete channel information.

$$C = \log_2 \det\left(\mathrm{I}_{n_r} + \frac{\rho}{n_t}\mathrm{H}\mathrm{H}^H\right) \quad (19)$$

In this equation, the symbol ρ represents the SNR, the symbol nt represents the number of transmit antennas, the symbol nr represents the number of receive antennas, and the symbol H represents the channel matrix.

On the other hand, throughput refers to the actual data rate that the communication system is able to achieve after taking into account a number of different variables such as protocol overhead, interference, and packet errors. It is essential to evaluate the MIMO-UAV system in real-world environments, and throughput is one of the most important factors to consider since it provides a more precise image of how the system functions from the point of view of the end users.

2.9.2. Bit Error Rate (BER) and Packet Error Rate (PER)

One must examine the Bit Error Rate (BER) in order to determine the degree of dependability that a communication system possesses. It is the proportion of erroneous bits that were received in comparison to the total number of bits that were broadcast over a particular period of time. In MIMO-UAV systems, where dependability can be just as crucial as data speed, maintaining a low bit error rate (BER) is essential for applications that need high precision or activities that cannot be compromised in terms of safety.

Packet Error Rate (PER) is a method that quantifies the proportion of packets that were received incorrectly in comparison to the total number of packets that were sent. This method is accomplished by applying the concept of Bit Error Rate (BER) to packets. When it comes to network protocols at the packet level, the PER is often considered to be the most important protocol. These protocols have the ability to significantly impact the performance of programmes that operate at higher levels. There are a number of factors that can influence the bit error rate (BER) and the bit

error rate (PER), including the signal-to-noise ratio, the modulation and coding schemes, and the channel parameters (Z. Liu et al., 2023).

2.9.3. Latency and Jitter

The amount of time that it takes for a signal to travel from its point of origin to its ultimate destination is referred to as latency also known as delay. For UAV communications, low latency is essential for a variety of applications, including real-time video streaming and remote control operations. A number of factors, including network queuing delays, processing delays at transmitters and receivers, and propagation delays, can all have an effect on latency.

Jitter, which refers to the variation in packet delay at the receiver, is a critical statistic for applications such as voice over internet protocol (VoIP) or online gaming that requires consistent timing. Jitter can be caused by a number of different factors, including but not limited to network congestion, changes in routing, and fluctuations in processing time at intermediate nodes. In the process of building and analysing MIMO-UAV systems, latency and jitter, which are two essential parameters for the user experience, are of the utmost importance (Z. Liu et al., 2023).

2.9.4. SNR and Signal-to-Interference-plus-Noise Ratio (SINR)

Using the SNR, which is a measure of signal quality, one may compare the intensity of the target signal to the strength of the noise in the surrounding environment. Both the capacity and reliability of a communication system are directly impacted by the SNR. A number of factors, including altitude, weather, and the propulsion systems of UAVs, have the potential to influence the SNR in the context of UAV communications.

To calculate the signal-to-noise ratio (SINR), both the signal-to-noise ratio and the intensity of interference in the denominator are taken into consideration. It is possible to obtain a more precise representation of the signal's quality when there are many transmitters present. When there are a large number of people or a variety of communication methods, the signal-to-noise ratio (SINR) is an extremely important factor for UAV operations. The goal of optimising MIMO-UAV systems is to achieve

high SNR and Signal-to-Information Ratio (SINR) values. These ratios and values show that the communication connection quality is exceptional (Z. Liu et al., 2023).

In this section, we will discuss each performance parameter in great detail and discuss how it influences the design decisions that are made and the effectiveness of MIMO-UAV communication systems that are now in operation. We will relate the mathematical formulations that are presented to real-world aspects such as the capabilities of the hardware, the impediments that are present in the environment, and the requirements of the application in order to obtain a comprehensive understanding of how to assess the performance of UAV communications.

2.10. MIMO Types and Their Relevance to UAV Communications

1. Spatial Multiplexing

Utilizes multiple antennas to transmit different data streams simultaneously, boosting data transmission rates and spectral efficiency without extra bandwidth or power.

Relevance to UAV Communications:

- High Data Rates: Ideal for real-time video streaming and large data transfers.

- Bandwidth Efficiency: Enhances spectral efficiency, maximizing bandwidth use.

2. Diversity Techniques

Uses multiple antennas to transmit the same signal, improving reliability by mitigating multipath fading.

Relevance to UAV Communications:

- Improved Reliability: Ensures consistent signals in challenging environments, crucial for search and rescue operations.

- Robust Connectivity: Maintains stable links in variable conditions like urban canyons.

3. Beamforming

Directs the signal using multiple antennas, enhancing signal strength and reducing interference.

Relevance to UAV Communications:

- Targeted Communication: Directs signals to specific ground stations or UAVs, improving efficiency.

- Extended Range: Increases communication range for broader operational areas.

4. Cooperative MIMO

Multiple UAVs form a virtual antenna array, providing MIMO benefits without needing multiple antennas on each UAV.

Relevance to UAV Communications:

- Networked Operations: Enhances performance in swarm operations for tasks like surveillance.

- Resource Efficiency: Reduces the need for multiple antennas on each UAV, saving weight and power.

CHAPTER THREE

ANALYSIS OF ANTENNA SELECTION TECHNIQUES

3.1. Introduction

This includes JTRAS, MRT/RAS, and TAS/MRC. When there are hurdles to direct communication between the source and the destination, such as poor channel conditions or physical barriers, these approaches are very important in a UAV-mediated dual-hop relay system. In particular, they are essential in situations when there are obstacles. The system model, which makes use of multi-antenna nodes and a three-dimensional coordinate framework, is used to explore the impact of environmental factors, such as urban density, on the transmission probabilities of LoS and NLoS based on the transmission probabilities. Within the context of the UAV relay system, the purpose of this section is to evaluate the effectiveness of these AS techniques by taking into consideration the influence that they have on the efficiency of communication under differing circumstances.

3.2. Overview of Antenna Selection Techniques

The TAS/MRC, JTRAS, and MRT/RAS antenna selection techniques are investigated in this study. These strategies are used in a relay communication system that is helped by UAVs. An UAV serves as an intermediary in a dual-hop relay system via which these techniques are implemented. When the system idea is put into practice, as seen in Figure 7, considerable obstacles or excessive fading hinder the source (S) and destination (D) from interacting directly with one another. Two-stage communication is made possible by the Decode-and-Forward (DF) relaying method, which requires the unmanned aerial vehicle to be positioned at an acceptable height.

Within the framework of the system paradigm, S, U, and D are all multi-antenna nodes, and each of them possesses N1, N2/N3, and N4 antenna. Within the context of a three-dimensional Cartesian coordinate system, this model is investigated by taking into consideration the precise locations and heights of the S, U, and D. When expressing the distances between S-U and U-D, Cartesian coordinates and the height of the UAV are utilised as the means of expression.

Particularly noteworthy is the fact that the article delves into the ways in which the environment (rural, urban, and dense urban) and the elevation angle influence the frequency of Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) transmissions between the unmanned aerial vehicle and ground nodes. The development of the probability formulae for LoS and NLoS transmissions has an effect on the mean route loss during the transmission process. Both the excessive path losses for LoS and NLoS propagations and the path loss models for LoS and NLoS that rely on the speed of light and carrier frequency are detailed in great detail in this article.

The purpose of this study is to investigate the effectiveness and utility of AS approaches in UAV-assisted relay communication systems by making use of these fundamental system and channel models. By utilising these models, we are able to gain a better understanding of the ways in which environmental factors and system design influence the efficiency of communication.

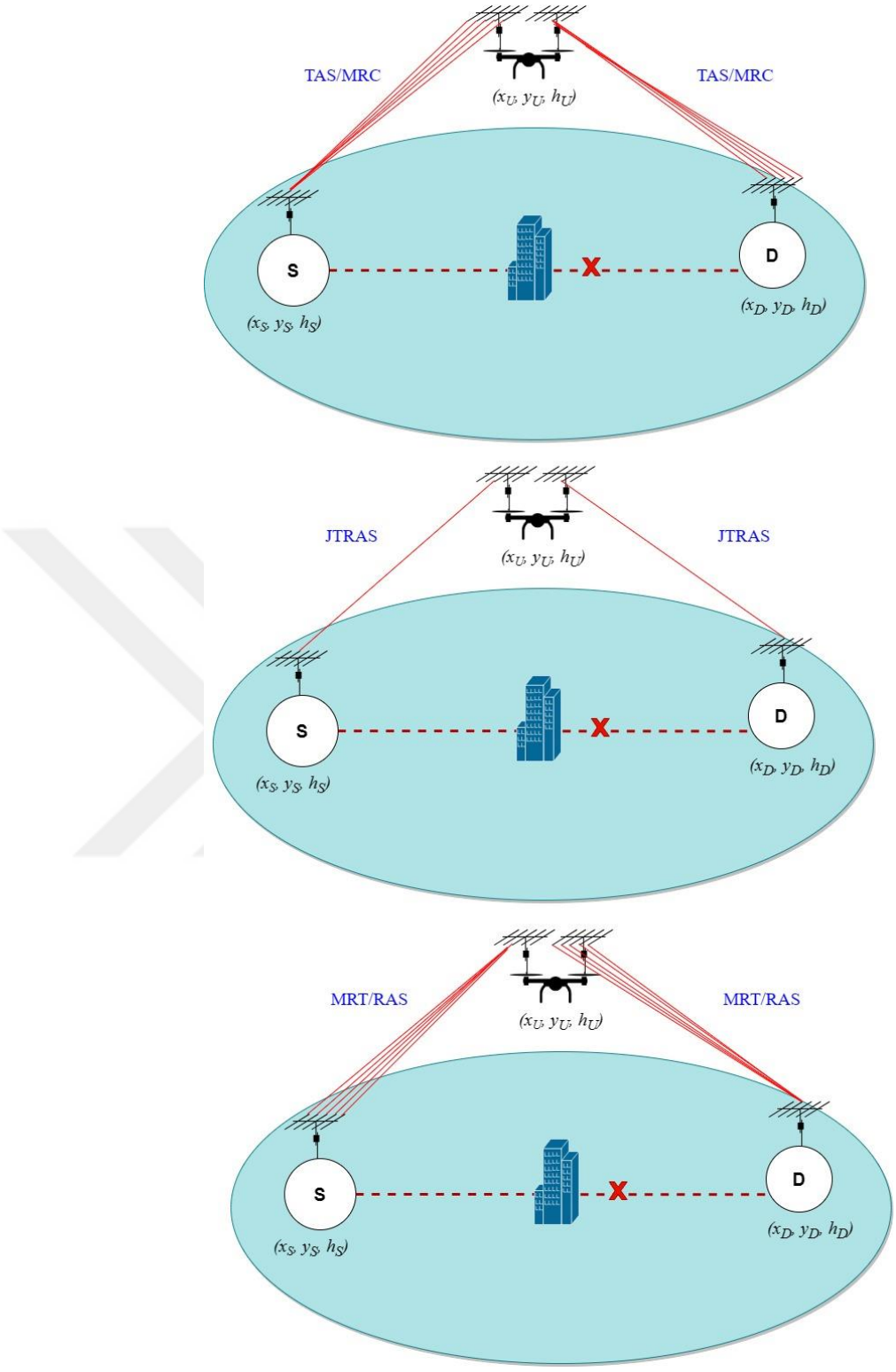

Figure 7. The system model for UAV-assisted network with different AS schemes

3.3. Unified Outage Probability Performance Analysis

It takes a lot of time and effort to do the Unified Outage Probability (OP) Performance Analysis for numerous AS methods in a relay system that is helped by UAVs. The research is carried out on the basis of a comprehensive model of the system, which includes a transmitter, a receiver, and a UAV that has the capability of transmitting data through the use of Decode-and-Forward (DF) technology. When calculating the end-to-end SNR for a variety of AS systems, it is necessary to take into account both Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) connections. In the context of Nakagami-m fading channels, the OP is estimated by employing expressions of the cumulative distribution function that are obtained from the highest-order statistics and multinomial coefficients. This rigorous process yields a precise closed-form formulation of the OP, which reflects the variety and complexity of real-world scenarios involving UAV-assisted communications. This formulation is the outcome of the rigorous methodology.

Considering the received signals at the U and D for various AS schemes ([signalTASMRC1], [signalTASMRC2], [signalJTRAS1], [signalJTRAS2], [signalMRTRAS1], and [signalMRTRAS2]) and DF relaying, the unified expression for end-to-end (e2e) SNR (γ_{SD}^{e2e}) can be written as

$$\gamma_{SD}^{\text{e2e}} = \min(\gamma_{SU}, \gamma_{UD}) \tag{20}$$

where γ_{SD} and γ_{UD} are the SNR values at the U and the D, respectively. The expressions of γ_{SD} and γ_{UD} for AS techniques are given in Table.1. Here, we assume $\gamma = \frac{P_S}{\sigma^2} = \frac{P_U}{\sigma^2}$, which is the average SNR.

Table 1. Comparative Analysis of Antenna Selection Schemes in UAV-Assisted Relay Systems

AS scheme	γ_{SU}	γ_{UD}
TAS/MRC	$\frac{\gamma}{\mathcal{L}_{\mathcal{SU}}} \parallel \mathrm{h}_{SU} \parallel^2$ $= \frac{\gamma}{\mathcal{L}_{\mathcal{SU}}} \max_{i=1,\ldots,N_1} \{\sum_{j=1}^{N_2} \left\lvert h_{SU}^{(i,j)} \right\rvert^2\}$	$\frac{\gamma}{\mathcal{L}_{\mathcal{UD}}} \parallel \mathrm{h}_{UD} \parallel^2$ $= \frac{\gamma}{\mathcal{L}_{\mathcal{UD}}} \max_{i=1,\ldots,N_3} \{\sum_{j=1}^{N_4} \left\lvert h_{UD}^{(i,j)} \right\rvert^2\}$

AS scheme	γ_{SU}	γ_{UD}
JTRAS	$\frac{\gamma}{\mathcal{L}_{\mathcal{SU}}}\lvert h_{SU}\rvert^2 = \frac{\gamma}{\mathcal{L}_{\mathcal{SU}}}\max\limits_{\substack{i=1,\ldots,N_1\\ j=1,\ldots,N_2}}\{\left\lvert h_{SU}^{(i,j)}\right\rvert^2\}$	$\frac{\gamma}{\mathcal{L}_{\mathcal{UD}}}\lvert h_{UD}\rvert^2 = \frac{\gamma}{\mathcal{L}_{\mathcal{UD}}}\max\limits_{\substack{i=1,\ldots,N_3\\ j=1,\ldots,N_4}}\{\left\lvert h_{UD}^{(i,j)}\right\rvert^2\}$
MRT/RAS	$\frac{\gamma}{\mathcal{L}_{\mathcal{SU}}}\parallel \mathrm{h}_{SU}\parallel^2 = \frac{\gamma}{\mathcal{L}_{\mathcal{SU}}}\max\limits_{j=1,\ldots,N_2}\{\sum\limits_{i=1}^{N_1}\left\lvert h_{SU}^{(i,j)}\right\rvert^2\}$	$\frac{\gamma}{\mathcal{L}_{\mathcal{UD}}}\parallel \mathrm{h}_{UD}\parallel^2 = \frac{\gamma}{\mathcal{L}_{\mathcal{UD}}}\max\limits_{j=1,\ldots,N_4}\{\sum\limits_{i=1}^{N_3}\left\lvert h_{UD}^{(i,j)}\right\rvert^2\}$

Now, the OP can be calculated as

$$\begin{aligned}\mathrm{OP} &= F_{\gamma_{SD}^{\mathrm{e2e}}}(x)\\ &= \mathcal{P}\left(\gamma_{SD}^{\mathrm{e2e}} \le x\right),\end{aligned} \tag{21}$$

where $\mathcal{P}(\cdot)$ denotes the probability operator and $x = \frac{\gamma_{th}\mathcal{L}_{\varphi}}{\gamma}$. Here, γ_{th} presents the threshold SNR value. Based on the expression of $\gamma_{SD}^{\mathrm{e2e}}$ in [e2e], the OP in [OP1] can be rewritten as

$$\begin{aligned}\mathrm{OP} &= \mathcal{P}(\min(\gamma_{SU},\gamma_{UD}) \le x)\\ &= 1-\left(1-F_{\gamma_{SU}}(x)\right)\left(1-F_{\gamma_{UD}}(x)\right)\\ &= F_{\gamma_{SU}}(x)+F_{\gamma_{UD}}(x)-F_{\gamma_{SU}}(x)F_{\gamma_{UD}}(x)\end{aligned} \tag{22}$$

In the following, the expressions of $F_{\gamma_{SU}}(x)$ and $F_{\gamma_{UD}}(x)$ in [OP2] are derived.

It is worthing that the channel gains between S and U for the first hop and U and D for the second hop are assumed to follow the Nakagami-m fading model. The cumulative distribution function (CDF) of the squared channel gain between the links in the first and second hops can be stated as

$$F_{\left\lvert h_{\varphi}^{(i,j)}\right\rvert^2}(x) = \frac{\Psi\left(m_{\varphi},\frac{m_{\varphi}x}{\Omega_{\varphi}}\right)}{\Gamma(m_{\varphi})} \tag{23}$$

where Ω_{φ} and m_{φ} are corresponding parameter of Nakagami fading.

Considering the expressions of γ_{SD} and γ_{UD} for AS techniques in Table .1 and basing on highest-order statistics, the unified expression for the CDF of γ_{SD} and γ_{UD} can be written as

$$F_{\gamma_\varphi}(x) = \left(\frac{\gamma\left(\alpha_\varphi, \frac{m_\varphi x}{\Omega_\varphi}\right)}{\Gamma(\alpha_\varphi)}\right)^{\beta_\varphi} \tag{24}$$

Here the values of α_φ and β_φ for different AS schemes are given in Table.2.

Table 2. Parameters for Different Antenna Selection Schemes in UAV-Assisted Communication

AS scheme	α	β
TAS/MRC	$\alpha_{SU} = m_{SU}N_2$ and $\alpha_{UD} = m_{UD}N_4$	$\beta_{SU} = N_1$ and $\beta_{UD} = N_3$
JTRAS	$\alpha_{SU} = m_{SU}$ and $\alpha_{UD} = m_{UD}$	$\beta_{SU} = N_1N_2$ and $\beta_{UD} = N_3N_4$
MRT/RAS	$\alpha_{SU} = m_{SU}N_1$ and $\alpha_{UD} = m_{UD}N_3$	$\beta_{SU} = N_2$ and $\beta_{UD} = N_4$

To simplify the expression in CDF: first, by utilizing an alternative expression of lower incomplete gamma functions, the CDF in equation 25 can be rewritten as

$$F_{\gamma_\varphi}(x) = \left(1 - e^{-\frac{m_\varphi x}{\Omega_\varphi}} \sum_{k=0}^{\alpha_\varphi - 1} \left(\frac{m_\varphi x}{\Omega_\varphi}\right)^k \frac{1}{k!}\right)^{\beta_\varphi} \tag{25}$$

Second, with the help of multinomial coefficients, the CDF in [CDF1] can be expressed as

$$F_{\gamma_\varphi}(x) = \sum_{p=0}^{\beta_\varphi} \sum_{k=0}^{p(\alpha_\varphi - 1)} \binom{\beta_\varphi}{p} (-1)^p \vartheta_k(p, \alpha_\varphi) x^k e^{-\frac{p m_\varphi x}{\Omega_\varphi}} \tag{26}$$

where $\vartheta_a(b, c)$ denotes multinomial coefficients, which can be written as

$$\vartheta_a(b, c) = \frac{1}{a e_0} \sum_{d=1}^{a} (d(b+1) - a)\, e_d \vartheta_{a-b}(b, c), a \geq 1 \tag{27}$$

where $e_d = (c/f)^d/d!$, $\vartheta_0(b, c) = 1$, and $\vartheta_a(b, c) = 0$ if $d > c - 1$. Finally, by utilizing [CDF2] to obtain the expressions of $F_{\gamma_{SU}}(x)$ and $F_{\gamma_{UD}}(x)$ and substituting them into [OP2], the closed-form expression of the OP can be written as in [OP3].

$$\begin{aligned} \text{OP} = & \sum_{p_1=0}^{\beta_{SU}} \sum_{k_1=0}^{p_1(\alpha_{SU}-1)} \binom{\beta_{SU}}{p_1} (-1)^{p_1} \vartheta_{k_1}(p_1, \alpha_{SU}) x^{k_1} e^{-\frac{p_1 m_{SU} x}{\Omega_{SU}}} + \sum_{p_2=0}^{\beta_{UD}} \sum_{k_2=0}^{p_2(\alpha_{UD}-1)} \binom{\beta_{UD}}{p_2} (-1)^{p_2} \vartheta_{k_2}(p_2, \alpha_{UD}) x^{k_2} e^{-\frac{p_2 m_{UD} x}{\Omega_{UD}}} \\ & - \sum_{p_1=0}^{\beta_{SU}} \sum_{k_1=0}^{p_1(\alpha_{SU}-1)} \sum_{p_2=0}^{\beta_{UD}} \sum_{k_2=0}^{p_2(\alpha_{UD}-1)} \binom{\beta_{SU}}{p_1} \binom{\beta_{UD}}{p_2} (-1)^{p_1+p_2} \vartheta_{k_1}(p_1, \alpha_{SU}) \vartheta_{k_2}(p_2, \alpha_{UD}) x^{k_1+k_2} e^{-\frac{p_1 m_{SU} x}{\Omega_{SU}} - \frac{p_2 m_{UD} x}{\Omega_{UD}}} \end{aligned} \tag{28}$$

3.4. Theoretical and Simulation-Based Validation

Within the context of UAV-assisted relay systems, the study utilised validation approaches that were founded on theory and simulation in order to demonstrate that various AS procedures performed effectively. In order to do this, it was necessary to compare the outcomes of Monte Carlo simulations with the theoretical outcomes, which were determined using closed-form OP expressions under Nakagami-m fading channels. In order to guarantee that the AS techniques were not only dependable but also usable, the simulations were carried out across a wide range of circumstances. This exhaustive examination of the AS approaches was made feasible by a stringent validation procedure that ensured the dependability of the theoretical models and their relevance to scenarios that occur in the actual world.

3.4.1. TAS/MRC scheme

Based on the TAS/MRC scheme, a single transmit antenna that provides the maximum summation of channel gains is chosen for both the S and the U in the first and second hops, respectively. Accordingly, the indices of the selected transmit antennas at the S (i_S^*) and U (i_U^*) can be stated, respectively, as

$$i_S^* = \underset{i=1,\dots,N_1}{\arg\max}\{\sum_{j=1}^{N_2}\left|h_{SU}^{(i,j)}\right|^2\} \tag{29}$$

and

$$i_U^* = \underset{i=1,\dots,N_3}{\arg\max}\{\sum_{j=1}^{N_4}\left|h_{UD}^{(i,j)}\right|^2\} \tag{30}$$

where $h_{SU}^{(i,j)}$ is the channel coefficient in the first hop between the ith transmit antenna of S and the jth receive antenna of U while $h_{UD}^{(i,j)}$ is the channel coefficient in the second hop between the ith transmit antenna of U and the jth receive antenna of D. Here, $|\cdot|$ refers to the absolute value.

The received signals at the U (y_U) and D (y_D) can be written, respectively, as

$$y_U = \sqrt{\frac{P_S}{\mathcal{L}_{SU}}}\mathrm{w}_{SU}\mathrm{h}_{SU}x^S + \mathrm{w}_{SU}\mathrm{n}_U \tag{31}$$

and

$$y_D = \sqrt{\frac{P_U}{\mathcal{L}_{UD}}} \mathrm{w}_{UD} \mathrm{h}_{UD} x^U + \mathrm{w}_{UD} \mathrm{n}_D \quad (32)$$

where P_S and P_U are the power transmission at the S and U, respectively, and x^S and x^U denote the signals at the S and U, respectively. In addition, h_{SU} is the fading channel coefficients of the first hop between the selected transmit antenna i_S^* of S and U while h_{UD} is the fading channel coefficients of the second hop between the selected transmit antenna i_U^* of U and D. Also, w_{SU} and w_{UD} are the optimal receive weight vectors at the U and D, respectively, with $\mathrm{w}_{SU} = \frac{\mathrm{h}_{SU}^H}{\|\mathrm{h}_{SU}\|}$ and $\mathrm{w}_{UD} = \frac{\mathrm{h}_{UD}^H}{\|\mathrm{h}_{UD}\|}$. n_U and n_D are zero mean complex additive Gaussian noise with σ^2, respectively at the U and D. Here, $(\cdot)^H$ denotes the Hermitian operator and $\|\cdot\|$ refers to the Norm value.

3.4.2. JTRAS scheme

Based on the JTRAS scheme, the transmit-receive antenna pair between the S and U, (i_S^*, j_U^*) is chosen in the first hop while the transmit-receive antenna pair between the U and D, (i_U^*, j_D^*) is selected in the second hop. Precisely, (i_S^*, j_U^*) has the highest channel gain between the transmit antennas of S and receiver antennas of the U and it can be expressed as

$$(i_S^*, j_U^*) = \underset{\substack{i=1,\dots,N_1 \\ j=1,\dots,N_2}}{\arg\max} \{ \left| h_{SU}^{(i,j)} \right|^2 \} \quad (33)$$

On the other hand, (i_U^*, j_D^*) has the maximum channel gain between the transmit antennas of U and receiver antennas of the D and it can be written as

$$(i_U^*, j_D^*) = \underset{\substack{i=1,\dots,N_3 \\ j=1,\dots,N_4}}{\arg\max} \{ \left| h_{UD}^{(i,j)} \right|^2 \} \quad (34)$$

The received signal of U and D can be respectively expressed as

$$y_U = \sqrt{\frac{P_S}{\mathcal{L}_{SU}}} h_{SU} x^S + n_U \quad (35)$$

and

$$y_D = \sqrt{\frac{P_U}{\mathcal{L}_{UD}}} h_{UD} x^U + n_D \quad (36)$$

where h_{SU} is the channel coefficient corresponding to the best link in the first hop, offering the highest channel gain between the S and U while h_{UD} is the channel coefficient corresponding to the best link in the second hop, offering the highest channel gain between the U and D. Additionally, n_U and n_D refer to the zero mean complex additive Gaussian noise with a variance of σ^2, respectively at the U and D.

3.4.3. MRT/RAS scheme

Based on the MRT/RAS scheme, single receive antennas that offer the maximum summation of channel gains are chosen for the U and D in the first and second hops, respectively. Accordingly, the indices of the chosen receive antennas at the U (j_U^*) and D (j_D^*) can be stated, respectively, as

$$j_U^* = \underset{j=1,\dots,N_2}{\arg\max}\{\sum_{i=1}^{N_1}\left|h_{SU}^{(i,j)}\right|^2\} \tag{37}$$

and

$$j_D^* = \underset{j=1,\dots,N_4}{\arg\max}\{\sum_{i=1}^{N_3}\left|h_{UD}^{(i,j)}\right|^2\} \tag{38}$$

The received signals at the U and D can be written, respectively, as

$$y_U = \sqrt{\frac{P_S}{\mathcal{L}_{SU}}}\mathrm{h}_{SU}\mathrm{u}_{SU}x^S + n_U \tag{39}$$

and

$$y_D = \sqrt{\frac{P_U}{\mathcal{L}_{UD}}}\mathrm{h}_{UD}\mathrm{u}_{UD}x^U + n_D \tag{40}$$

where h_{SU} is the fading channel coefficients of the first hop between the selected receive antenna j_U^* of U and S while h_{UD} is the fading channel coefficients of the second hop between the selected receive antenna j_D^* of D and U. Additionally, h_{UD} u_{SU} and u_{UD} are the optimal transmit weight vectors at the S and U, respectively, with $\mathrm{u}_{SU} = \frac{\mathrm{h}_{SU}^H}{\|\mathrm{h}_{SU}\|}$ and $\mathrm{u}_{UD} = \frac{\mathrm{h}_{UD}^H}{\|\mathrm{h}_{UD}\|}$.

It can breifly summarize the above methods as in Table.3 as:

Table 3. Comparative Analysis of AS Schemes in UAV-Assisted Relay Systems

AS	Complexity	Performance	Suitability for UAV	Pros	Cons
TAS/MRC	Moderate	High reliability and strong signal quality	Urban environments, high mobility scenarios	- Provides good reliability in fading environments - Strong signal reception through MRC	- Moderate computational complexity - Requires multiple antennas
JTRAS	High	Optimal performance with highest channel gain	Diverse environments, resource-intensive applications	- Best possible channel gain - Adaptable to varying channel conditions	- High computational complexity - Intensive on resources, may not be suitable for all UAVs
MRT/RAS	Moderate to High	Strong signal reception and robustness	Long-distance communication, variable link quality	- Enhances robustness in poor channel conditions - Suitable for long-distance communication	- High computational complexity - Focuses more on receive side, may not optimize transmit side

3.5. Conclusion

In the final portion of this chapter, a summary of the findings from the inquiry into the techniques of antenna selection in UAV-assisted relay systems is presented. By synthesising the findings of performance analysis for the TAS/MRC, JTRAS, and MRT/RAS methodologies, it brings to light the advantages and disadvantages of each of these particular methods. The theoretical and simulated validations provide further evidence for the practical utility of the methodologies. This chapter provides an overview of how various AS approaches may be utilised in UAV communication systems in an effective manner, hence laying the framework for future research and advances in the field.

CHAPTER FOUR

ASYMPTOTIC ANALYSIS AND PERFORMANCE EVALUATION

4.1. Introduction

The methods of AS in UAV -assisted relay systems are examined in great detail in Chapter 4 of this research. In the introduction, a comprehensive asymptotic assessment of various approaches is presented, which evaluates the features of their performance over the long run. The next stage is to conduct a comprehensive evaluation by means of simulations, which will provide facts to support the findings drawn from the theoretical analysis. The chapter then moves on to a comparison and assessment section, where it compares and contrasts the various AS strategies to demonstrate how they compare to one another and what potential repercussions they may have. In the end, a review of the findings is presented, along with some ideas on the potential future developments in the field of communication systems for UAVs.

4.2. Asymptotic Analysis of Antenna Selection Techniques

4.2.1. Theoretical Framework for Asymptotic Analysis

The major focus of the theoretical framework for the asymptotic analysis of antenna selection techniques in UAV-assisted networks is on evaluating performance restrictions under high SNR circumstances. This is the core focus of the framework. This study is essential for gaining an understanding of the limits of system capabilities, particularly in light of the fact that traditional performance measurements are becoming closer and closer to their theoretical limits. Obtaining formulae that characterise the behaviour of the OP is an essential part of the asymptotic analysis in this situation, which occurs as the SNR becomes closer and closer to infinity. The purpose of these expressions is to shed light on the underlying trade-offs between system complexity, antenna design, and performance gains. A better understanding of how different antenna selection techniques, such as TAS/MRC, JTRAS, and MRT/RAS, scale with increasing SNR may be achieved by using these expressions.

Specifically, the array and diversity benefits of the system are brought to light by the reduction of the resulting formulae for OP under high SNR conditions and the investigation of the asymptotic behaviour. The consequence of this reduction is frequent expressions that incorporate fundamental elements such as the number of antennas and the fading characteristics of the channels. Asymptotic analysis is a valuable tool that deconstructs the fundamental constraints of antenna selection techniques. It is used for optimising and building communication networks that are helped by UAVs. This is an extremely important factor in understanding how the performance and reliability of the system is affected by the various antenna selection strategies that are utilised in high-pressure circumstances.

4.2.2. Long-Term Performance Characteristics

In UAV aided networks, antenna selection algorithms have significant long-term performance characteristics that are essential for comprehending how the system operates in a variety of environmental conditions over extended periods of time. In this section, we will describe the statistical metrics that characterise the success of several antenna selection approaches over the long run. These methods include TAS/MRC, JTRAS, and MRT/RAS that are among those addressed. During the course of this investigation, quantitative measurements are utilised. These include the average outage probability (AOP) and the mean capacity across extended time periods. For instance, finding the AOP may be accomplished by entering the values of the rate parameter (λ) and the probability density function of the signal-to-noise ratio (f(x)) into the formula that was shown before.

$$AOP = \int_0^\infty \left(1 - e^{-\lambda x}\right) f_X(x) dx \qquad (41)$$

By examining the cumulative distribution function (CDF) of the system's SNR, one may gain an understanding of the probability distribution around the SNR values over time. With the assistance of this study, one may have a greater understanding of optimal performance as well as the dependability of the system. The equation gives the CDF, where γ is the signal-to-noise ratio. An in-depth study of these long-term performance characteristics is required in order to construct dependable communication networks that are helped by UAVs and are able to maintain their performance in a wide variety of operational scenarios that are constantly evolving.

$$F_{\gamma}(x) = P(\gamma \leq x) \quad (42)$$

4.2.3. Implications for UAV Relay System Design

The purpose of this section is to investigate the potential applications of the theoretical findings obtained from the asymptotic and long-term performance evaluations in order to improve the performance of UAV relay systems. On the basis of the findings from antenna selection techniques, the primary focus is on the development of realistic standards for communication networks that make use of UAVs. To provide one example, when it comes to UAV relays, understanding how many antennas to utilise in comparison to the diversity gain that can be achieved has an effect on both the physical design and the strategies for resource allocation. According to the findings of the research, it is particularly important in dynamic aerial scenarios to strike a balance between the complexity of the system and the requirements for performance.

The optimisation of flight routes, the adjustment of height, and the orientation of antennas based on statistical characteristics of communication channels are all examples of operational procedures that UAV relays have to take into consideration. In order to develop adaptive algorithms that are able to make adjustments to the settings of the system in real time in order to accommodate new circumstances and the requirements of the network, long-term performance statistics are utilised as a reference. For the purpose of ensuring the dependability, efficiency, and scalability of communication systems that are aided by UAVs (UAVs), it is essential to integrate theoretical studies with practical design considerations during the design process.

4.3. Performance Evaluation through Simulations

4.3.1. Introduction to Simulation Parameters

In our simulations, several key parameters were meticulously chosen to model a realistic UAV-assisted communication network. These include the spatial coordinates of the source (x_S, y_S, h_S), UAV (x_U, y_U, h_U), and destination (x_D, y_D, h_D), set to (0,0,0) m, (100,0,1000) m, and (200,0,0) m, respectively. Other critical parameters such as the angular spread (ω), path-loss exponent (ϖ), speed of light (c), carrier frequency (f_c), relative permittivity (ϵ), and coefficients for line-of-sight

(ξ^los) and non-line-of-sight (ξ^nlos) scenarios are also incorporated. The simulation reflects a comprehensive scenario accounting for realistic propagation and environmental conditions.

4.3.2. Performance Analysis based on Figures.

Additionally, the OP performance of the TAS/MRC system is depicted in Figure 8 as a function of the average SNR. According to the study, the findings of the asymptotic, analytical, and simulated simulations are completely in agreement with one another at high SNR levels. The expansion of both the broadcast and receive antennas results in a significant improvement in the overall performance of the OP. The results of the tests indicate that TAS/MRC performs better than other antenna configurations in terms of enhancing SNR gains and minimising OP. Some of the configurations that are evaluated are (1, 1, 1, 1) and (2, 1, 2, 1).

See Figure 9 for an illustration of the OP performance of the JTRAS method. This demonstrates that the performance of the OP is significantly improved due to an increase in the number of antennas present at each node. When we compare JTRAS to single-antenna and other basic antenna designs, we find that it performs better overall, particularly in situations when the channel circumstances are better. This is especially true in situations where the channels are better.

As can be observed in Figure 10, the OP performance of the MRT/RAS system sees a significant improvement when more antennae are utilised and when channel conditions are improved. In specifically, the efficiency of MRT/RAS in enhancing performance is demonstrated by comparing different antenna designs. This is done in settings when Nakagami-m fading characteristics are present.

With the assistance of these simulations, it is possible to gain a better understanding of and improve the implementation of a variety of antenna selection algorithms in UAV-assisted networks. The optimisation of antenna layout and the dependability of communication are two of the most significant characteristics of communication systems that are based on UAVs (UAVs), and they provide a basis for both of these aspects.

This section examines the various techniques to antenna selection in UAV-assisted communication networks, as well as the simulated performance evaluation of

those approaches. The simulations are being run with the intention of putting the theoretical models to the test and gaining an understanding of how the system behaves in actual use cases. Through the utilisation of a Monte Carlo simulation technique, performance measures such as Channel Capacity and OP are taken into consideration and assessed. For example, as seen in Figure 8, the simulations demonstrate how the optimisation process is affected by varying the number of antennas.

Without initially completing a performance evaluation of antenna selection procedures through the use of simulations, this research would not be considered complete. The theoretical findings will be supported by the real facts that will be provided by this. Figure 9 illustrates the OP performance of the JTRAS scheme in the UAV-assisted network. This performance was evaluated using a variety of fading settings and antenna configurations.

Figure 10 demonstrates that the MRT/RAS approach is effective in a similar manner. This picture presents a comparison of the performance of the OP under various channel conditions and antenna counts. It demonstrates how the MRT/RAS scheme has the potential to transform UAV-assisted networks into communication networks that are significantly more dependable.

In addition to examining certain approaches, the simulations take into account a variety of characteristics, such as the height of the UAV, flight patterns, and environmental implications. The optimisation of UAV relay networks is directed by an all-encompassing strategy that ensures a comprehensive picture of the performance of the system.

The findings of the simulation are essential for actual implementations since they provide a realistic evaluation of the behaviour of the system under a variety of various operating settings. The construction of communication networks that are helped by UAVs (UAVs) that are dependable, efficient, and extendable is tremendously supported by these results.

In conclusion, the research conducted through simulation offers valuable information that can be utilised for the management and implementation of communication systems that are supported by UAVs (UAVs), in addition to providing support for theoretical studies. This combination of theoretical and practical research

can serve as a foundation for future advancements in the technology of UAV communication.

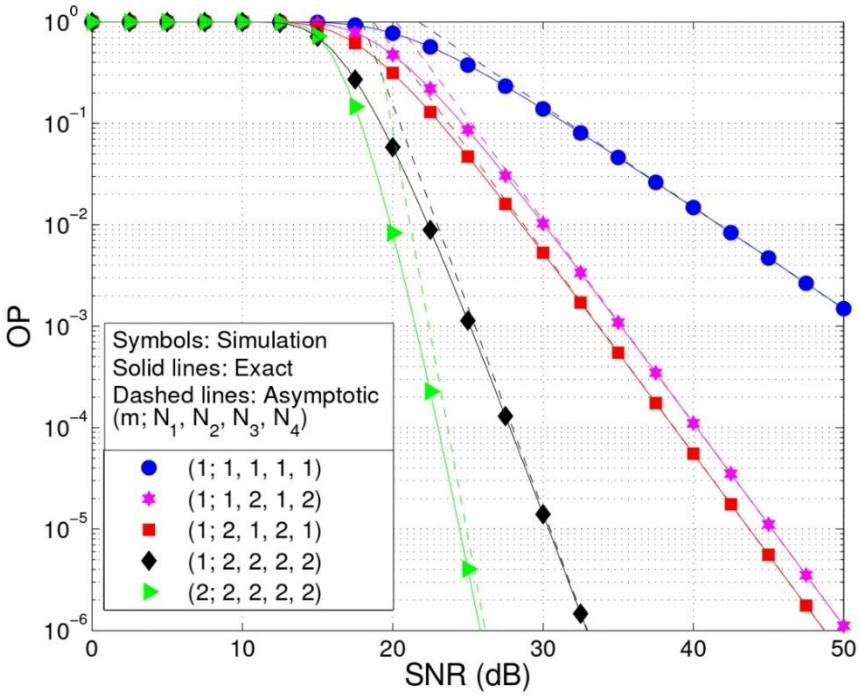

Figure 8. Impact of Antenna Variation on OP in TAS/MRC Scheme

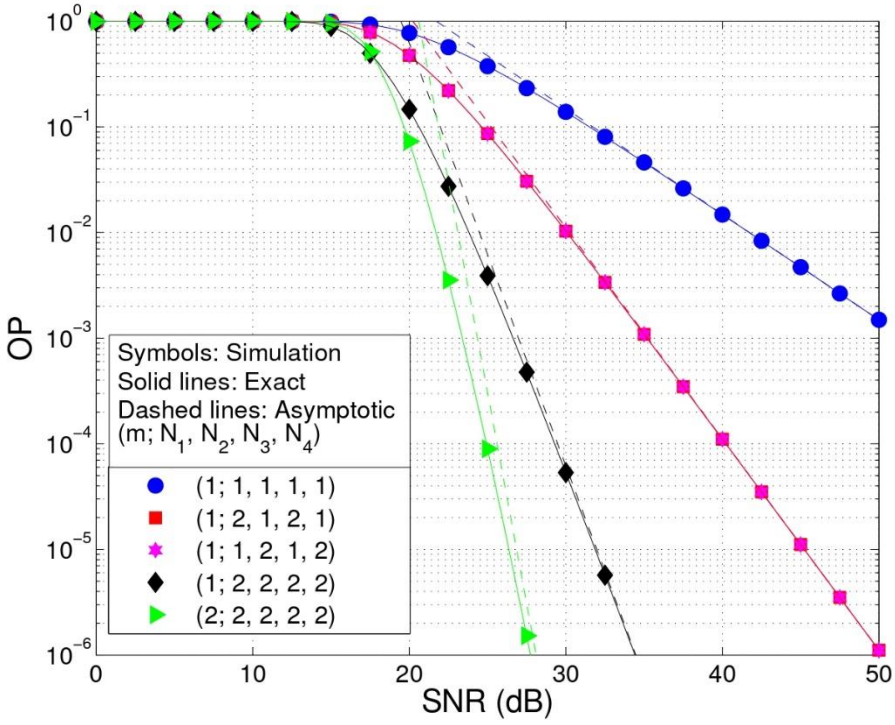

Figure 9. OP Performance of JTRAS Scheme

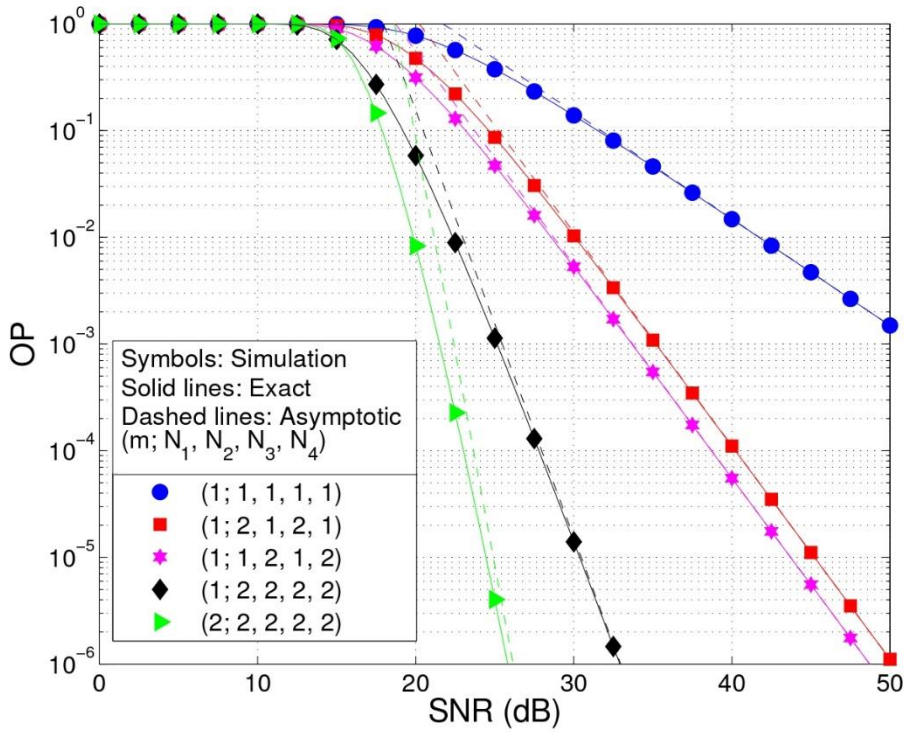

Figure 10. OP Performance of MRT/RAS Scheme

4.4. Comparative Assessment and Implications

Similar to TAS/MRC, JTRAS, and MRT/RAS, the simulations also allow for comparisons to be made between various antenna selection procedures. This type of comparative analysis is absolutely necessary in order to determine which antenna selection approach is the most suitable for a variety of circumstances, such as SNR levels and fading settings. A comprehensive summary of this comparison is presented in Figure 11, which illustrates the performance of each scheme under a variety of different settings respectively.

Furthermore, the simulations investigate the ways in which the mobility and height of the UAVs (UAVs) influence the operation of the communication network. This section is particularly significant since it pertains to the practical use of UAVs in the real world. Through the modification of the simulations' altitude and mobility parameters, the research investigates the most effective ways to position and move UAVs in order to maximise the effectiveness and reliability of the network.

It is also possible to represent aspects of the surrounding environment, such as the weather and the physical impediments that are there. These factors are extremely important since they have the ability to significantly impact both the intensity of the signal and the resilience of the network. Through the incorporation of genuine environmental elements into the simulations, the research offers a more comprehensive understanding of the functioning of UAV-assisted networks in real-world contexts.

Last but not least, the simulations set the framework for the development of operating and design standards for communication networks that are supported by UAVs. These simulations provide valuable insights that are used to influence important design decisions, such as the placement of antennas, the routing protocols for UAVs, and the architecture of the network. Furthermore, this all-encompassing strategy not only validates the theoretical conclusions, but it also ensures that they are applicable to the design and optimisation of communication systems that are helped by UAVs.

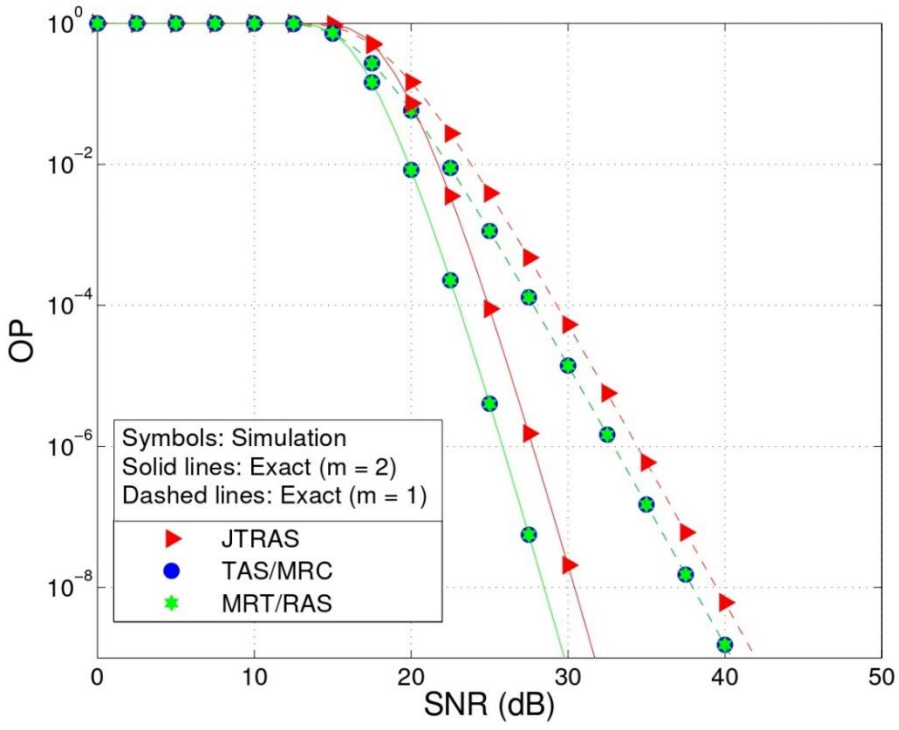

Figure 11. Comparative Performance of Different Antenna Selection Schemes

4.5. Conclusion

A comprehensive study of antenna selection strategies for use in UAV-assisted networks has been provided in this chapter. Particular attention has been paid to the asymptotic analysis and long-term performance features of these aforementioned strategies. Using theoretical frameworks and simulations, this research has demonstrated how these methodologies have a significant impact on the design of UAV relay systems. The findings demonstrate how critical it is to maximise the effectiveness of communication by taking into consideration environmental conditions and antenna configurations. This chapter not only contributes to our understanding of UAV communication systems, but it also prepares the path for future advancements in the design and implementation of networks that are dependent on UAVs.

CHAPTER FİVE

COMPARATIVE ANALYSIS AND DISCUSSION

5.1. Comparative Analysis of AS Techniques

There is a discernible distinction between the three antenna selection techniques that are utilised in UAV-assisted networks, namely TAS/MRC, JTRAS, and MRT/RAS. These approaches are distinguished by their characteristics and performance measurements. In spite of the fact that TAS/MRC achieves superior OP performance, it is more difficult to deploy, and this difficulty is especially obvious in systems that have a greater number of transmit and receive antennas. Despite the fact that JTRAS offers enhanced OP with a greater number of antennas, it stands out due to the fact that it takes a streamlined method that only makes use of one RF chain. MRT/RAS is an excellent choice for high-performance applications due to the fact that it is more complicated than TAS/MRC and offers performance benefits that are equivalent to those of TAS/MRC. The practical usefulness of the three approaches varies depending on the requirements of the network and the complexity of the network; nonetheless, all three methods demonstrate scalability with regard to the number of antennas and the channel conditions.

Table 3 presents a comparison of the various approaches that are utilised in the selection of antennas for UAV-assisted networks. The following table provides a comprehensive comparison of three significant antenna selection methods: TAS/MRC, JTRAS, and MRT/RAS methodology. Through the use of criteria such as Outage Probability, Antenna Configurations, Channel Conditions, System Complexity, Scalability, and Practical Implementation, it analyses and contrasts each technique, shedding light on the benefits and drawbacks associated with each method in a variety of UAV-assisted communication network situations.

Table 3. Comparative Analysis of Antenna Selection Techniques in UAV-Assisted Networks

Criteria	TAS/MRC Technique	JTRAS Technique	MRT/RAS Technique
OP	Improves with increased antennas; 19 dB, 7 dB, 5 dB SNR gains at an OP of 10^(-2) in (2,2,2,2) configuration for m=1	Significant improvement with increased antennas; about 17 dB, 5 dB, and 5 dB SNR gains at an OP of 10^(-2) in (2,2,2,2) configuration for m=1	Enhanced OP with increased antennas; about 19 dB, 7 dB, and 5 dB SNR gains at an OP of 10^(-2) in (2,2,2,2) configuration for m=1
Antenna Configurations	Configurations like (1,1,1,1), (2,1,2,1), and (2,2,2,2) examined; TAS/MRC offers significant performance enhancement	Configurations like (1,1,1,1), (2,1,2,1), and (2,2,2,2) tested; JTRAS shows superior performance than simpler configurations	Configurations like (1,1,1,1), (2,1,2,1), and (2,2,2,2) analyzed; MRT/RAS outperforms other cases
Channel Conditions	Enhanced OP performance with improved channel conditions (m=1 and m=2 scenarios)	OP performance improves with channel condition enhancement (m=1 and m=2 scenarios)	Improved OP performance with better channel conditions (m=1 and m=2 scenarios)
System Complexity	Relatively higher complexity due to multiple RF chains	Reduced complexity, uses only a single RF chain	Similar to TAS/MRC, involves higher complexity due to multiple RF chains
Scalability	Scalable with antenna number and channel conditions	Scalable but limited by the single RF chain constraint	Scalable with antenna number and channel conditions
Practical Implementation	Effective in improving SNR and OP, suitable for scenarios requiring high reliability	Good balance between performance and system simplicity, suitable for less complex network requirements	Offers performance benefits similar to TAS/MRC, suitable for high-performance applications

5.2. Discussion of Results and Implications

The evaluation of TAS/MRC, JTRAS, and MRT/RAS methodologies has led to the derivation of significant conclusions for UAV-assisted networks. The findings indicate that there is a tradeoff between the extent of the system's complexity and its level of efficiency. The TAS/MRC and MRT/RAS systems both offer superior performance in terms of the Outage Probability, despite the additional complexity they present. Despite the fact that JTRAS offers considerable improvements, it is more straightforward and functions more effectively with network setups that are less difficult. These findings, which have significant repercussions for the design of

networks, bring to light the need to strike a balance between performance and the limits that are really imposed by deployment. Adapting each strategy to a variety of channel circumstances and operational scenarios is the guiding principle behind the development of communication systems that are dependable, efficient, and scalable with the assistance of UAVs. As this discussion has demonstrated, it is essential to take into consideration both the technical performance and the practical restrictions of UAV communication technology in order to make progress.

5.3. Practical Applications and Future Perspectives

This study extrapolates its findings into settings that are based on the real world in order to highlight the potential impacts that the TAS/MRC, JTRAS, and MRT/RAS approaches might have on communication networks that are helped by UAVs. UAV networks have the potential to significantly improve a number of real-world sectors, including emergency response, environmental monitoring, and urban communication infrastructure applications. Based on the findings of this study, more research might be conducted on a variety of issues, such as the development of artificial intelligence-driven network management systems, adaptive antenna selection algorithms, and the integration of technologies beyond 5G. Because of these advancements, the effectiveness, coverage, and reliability of communications that are helped by UAVs might noticeably increase.

5.4. Conclusion

This chapter, which successfully connects theoretical models with actual reality, provides insights for future advancements in UAV communications. This article highlights the relevance of adapting antenna techniques to match the demands of networks, and it also suggests that new routes for research into enhancing UAV-assisted communication systems may be explored in light of the progress that has been made in technology and the possible applications that may be developed in the future.

CONCLUSION AND RECOMMENDATIONS

As part of this study, a comprehensive investigation of the efficiency of multiple AS methods in a relay communication system that makes use of UAVs as aerial relays has been carried out. Studies have been conducted to investigate the impact that the three AS techniques—TAS/MRC, JTRAS, and MRT/RAS—have on the performance of the system. The creation of a closed-form equation for the OP under Nakagami-m fading channels has resulted in the acquisition of significant insights into the dependability of these systems. In addition, an asymptotic equation has been developed in order to characterise the array and diversity benefits. This equation draws attention to the potential enhancements in system performance that are associated with the various AS techniques. These findings from the research are essential because they offer a strong theoretical framework for gaining an understanding of the intricacies of AS in UAV relay networks and for the development of efficient communication systems.

In order to provide support for the analytical findings, Monte Carlo simulations were carried out. These simulations proved the correctness of the models as well as their practical applicability. To a large extent, the results are consistent with the theoretical statements. According to the calculations, the overall performance of the OP may be greatly improved by increasing the number of antennas that are used for broadcasting and receiving at each node. In situations where the channel conditions are more favourable, the effectiveness of the OP is enhanced. JTRAS is not as excellent as the TAS/MRC and MRT/RAS systems in terms of performance measurements; however, JTRAS does have the benefit of being simpler than the other schemes. The fact that the performance of the OP degrades with increasing distance from the ground nodes is evidence of the relevance of the position of the UAV in communication systems.

On the basis of these findings, it is recommended that one increase the size and weight of antenna arrays in systems where it is possible to do so in order to obtain greater performance. It is imperative that the development of trustworthy communication links places a high priority on the enhancement of channel conditions via the utilisation of advanced signal processing and the strategic positioning of UAVs.

Prior to making a decision about an AS strategy, it is essential to carefully consider the benefits and drawbacks associated with performance and complexity. TAS/MRC or MRT/RAS are ideal options for applications that place a high priority on reliability, whereas JTRAS is the best option for circumstances in which simplicity and affordability are of the utmost importance respectively.

The optimisation of operational performance also necessitates the development of a UAV deployment strategy that reduces the distance to ground nodes. In order to accomplish this objective, it is possible that it will be essential to develop dynamic routing and positioning algorithms that are sensitive to the operating environment. Future research should study the usage of many UAVs as relays and investigate how other environmental factors, such as urban infrastructure and weather, influence the efficiency of AS. This is a recommendation that should be taken into consideration. As a result of these advancements, UAV relay networks will be able to advance, which will allow them to better manage the intricate and ever-increasing requirements of contemporary communication.

Future research should explore the use of multiple UAVs as relays and investigate how factors like urban infrastructure and weather affect AS efficiency. Multi-UAV systems could enhance coverage, reliability, and throughput. Optimal deployment strategies, including cooperative communication techniques, should be examined to improve network performance.

Integrating machine learning and AI for dynamic antenna selection and UAV positioning is another promising area. These technologies could enable adaptive decision-making, leading to more efficient and robust networks.

Lastly, addressing regulatory and security challenges is crucial. Ensuring secure, compliant communication links amid various threats and constraints is essential for practical deployment.

By tackling these areas, future research can significantly advance UAV relay networks, ensuring they meet the complex demands of modern communication systems.

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