WIRELESS COOPERATIVE SCHEME FOR NEXT GENERATION UAVS–ASSISTED CELLULAR NETWORKS IN DISASTER AREAS

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Mohammed Abdullah Ali AFANDI

ABSTRACT

Master Thesis

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This study makes a significant contribution to the field of telecommunication infrastructure during natural disasters. It proposes a novel solution utilizing unmanned aerial vehicles (UAVs) equipped with 5G communication technology.

Natural disasters can disrupt telecommunication infrastructures, leaving cellular networks inaccessible and hindering the progress of first responders. Multi-UAV communication is also necessary to improve energy efficiency, capacity, and spectrum efficiency and establish communication services for ad-hoc networks without centralized networking.

The proposed models for cooperative UAV relay in wireless communication show promising results for improving wireless communication in disaster areas using the criterion of high Signal to noise ratio as an algorithm to establish the communication between nodes to enhance public safety networks' ability to respond to emergency calls and share critical information during natural disasters. The simulation results and performance analysis provide valuable guidelines for optimizing resource allocation regarding energy efficiency, spectrum efficiency, and capacity for an effective communication network in disaster areas.

The proposed system can aid rescue operations by connecting people in affected areas and allowing them to communicate with first responders. The study emphasizes the need for disaster management strategies and public safety and emergency communications to ensure effective disaster recovery. The study on managing resources during a disaster event using multi-hop U2U communication for the importance of effective disaster management strategies of public safety and emergency communications systems.

**Key Words : ** Natural disasters, Unmanned aerial vehicles (UAVs), Çok İHA ad-hoc ağları, İşbirlikçi İHA, Felaket Kurtarma, 5G And B5G.
**Science Code : ** 90523

ÖZET

Yüksek Lisans Tezi

AFET BÖLGESİNDE YENİ NESİL İHA'LAR DESTEKLİ HÜCRESEL AĞ İÇİN KABLOSUZ İŞ BİRLİĞİ PROGRAMI

Mohammed Abdullah Ali AFANDI

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
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Bu çalışma, doğal afetler sırasında telekomünikasyon altyapısı alanına önemli bir katkı sağlamaktadır. 5G iletişim teknolojisi ile donatılmış insansız hava araçlarını (İHA) kullanan yeni bir çözüm önermektedir.

Doğal afetler telekomünikasyon altyapılarını bozabilir, hücresel ağları erişilemez hale getirebilir ve ilk müdahale ekiplerinin ilerlemesini engelleyebilir. Çoklu İHA iletişimi, enerji verimliliğini, kapasiteyi ve spektrum verimliliğini artırmak ve merkezi ağ olmadan geçici ağlar için iletişim hizmetleri oluşturmak için de gereklidir.

Kablosuz iletişimde kooperatif İHA rölesi için önerilen modeller, kamu güvenliği ağlarının acil durum çağrılarına yanıt verme yeteneğini geliştirmek için düğümler arasındaki iletişimi kurmak için bir algoritma olarak yüksek Sinyal gürültü oranı kriterini kullanarak afet bölgelerinde kablosuz iletişimi geliştirmek için umut verici sonuçlar göstermektedir. ve doğal afetler sırasında kritik bilgileri paylaşın. Simülasyon sonuçları ve performans analizi, afet bölgelerinde etkili bir iletişim ağı için enerji verimliliği, spektrum verimliliği ve kapasite ile ilgili kaynak tahsisini optimize etmek için değerli kılavuzlar sağlar.

Önerilen sistem, etkilenen bölgelerdeki insanları birbirine bağlayarak ve ilk müdahale ekipleriyle iletişim kurmalarını sağlayarak kurtarma operasyonlarına yardımcı olabilir. Çalışma, etkili bir felaket kurtarma sağlamak için afet yönetimi stratejilerine ve kamu güvenliği ve acil durum iletişimine duyulan ihtiyacı vurgulamaktadır. Kamu güvenliği ve acil durum iletişim sistemlerinin etkili afet yönetimi stratejilerinin önemi için çok sekmeli U2U iletişimi kullanılarak bir afet olayı sırasında kaynakların yönetimi üzerine çalışma.

Anahtar Kelimeler : Doğal afetler, İnsansız hava araçları (İHA'lar) 5G ve B5G.
Bilim Kodu : 90523

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ABBREVITIONS INDEX

ABBREVIATIONS

1G : First Generation
6G : Sixth Generation
A2A : Air-to-Air
A2G : Air-to-Ground
B5G : Beyond 5G
CS : Cooperative Schemes
DZ : Disaster Zones
GBS : Ground-Based Stations
GCS : Ground Control Stations
EE : Energy Efficiency
IOT : Internet of Things
LAP : Lower Altitude Platform
LOS : Line of Sight
NLOS : Non-Line of Sight
MULTI-UAV : Multi-Unmanned Aerial Vehicle
SE : Spectrum Efficiency
SAR : Search and Rescue
SPR : Shortest Path Routing
SINR : Signal-to-Interference-Plus-Noise Ratio
CN : Centralized Networking
CUR : Cooperative UAV Relay
QOS : Quality of Service
ND : Natural Disasters
RO : Rescue Operations
DM : Disaster Management
D2D : Device-to-Device

EC : Emergency Communications
EDR : Effective Disaster Recovery
UAV : Unmanned Aerial Vehicle
U2U : UAV to UAV
U2G : UAV to the ground station
UAVANET : UAV Ad-hoc Network

CHAPTER 1

INTRODUCTION

Natural disasters can have a catastrophic impact on telecommunication infrastructures, leaving cellular infrastructure network services vulnerable and unable to provide essential coverage [1]. This vulnerability can result from the disaster, which can impede the ability of first responders to communicate with disaster zone areas [2]. In emergencies, prompt communication and response by first responders can make a critical difference in saving lives [3]. Therefore, it is crucial to establish reliable and efficient connectivity in disaster zones. In this regard, wireless cooperation with UAVs network is an innovative solution that can provide reliable and efficient connectivity, even in challenging conditions. The UAVs Network can offer quick deployment, flexibility, and connectivity in remote areas, making it an ideal solution for disaster relief operations.

Moreover, UAVs can be equipped with various communication technologies such as LTE, Wi-Fi, and satellite communication systems, which can provide reliable communication services to disaster zones. Therefore, integrating UAVs Network with wireless communication technologies can significantly enhance the effectiveness of disaster response and recovery efforts.

1.1. PROJECT BACKGROUND

A significant amount of published studies describe the role of Unmanned Aerial Vehicle (UAV) networks in ensuring communication during natural disasters that frequently occur in various parts of the world [4]. Existing research into Wireless Cooperative Scheme has shown that it is a promising technology for future-generation networks, i.e., fifth generation (5G) and beyond.

In wireless networks, cooperation can benefit from Internet of Things (IoT) platforms to enable solutions that improve people's lives and the quality of service (QoS). UAV ad-hoc networks, as an encouraging framework quickly gaining traction in upcoming wireless communications, such as the 5G network [5]. Therefore, multi-UAV cooperative communication schemes can help provide connectivity to transfer and route data traffic among nodes in wireless networks [6]. In wireless and UAV communications, a centralized mechanism refers to a network architecture where a central node manages and coordinates the communication between all the devices in the network.

Moreover, cooperative communication schemes promise to improve energy efficiency, capacity, and spectrum efficiency [7]. Furthermore, as a hybrid of ad-hoc and centralized communication mechanisms, UAVs network enables better communication services for ad-hoc networks without the need to use centralized networking topology [8].

This project aims to develop the UAV cooperative scheme that enables communication in dead zones (out of coverage). This can be achieved by collaborating or partnering strong user equipment (UE) (strong UE refers to strong relation with the (active Base station (BS_1)), i.e. high SNR value) with weak UE (weak UE refers to poor relation with the base stations i.e., low SNR value) using UAV network. This, in turn, will revive the communication system in dead areas (disaster areas).

In addition, UAVs have promoted several capabilities to establish communication between Air-to-Air nodes and Air-to-Ground nodes in out-of-coverage areas. UAV communication, particularly in Air-to-Air and Air-to-ground scenarios, has been focused on developing new mobile service channels that reduce network traffic and power consumption while maintaining reliable communication. Therefore, a large and growing body of literature has investigated UAV communications in the public safety network to avoid dropping and fading networks through natural disasters. In multi-UAV communication, the focus is on ensuring the availability of radio resources for communication channels between sources and destinations through established links [9]. While the researchers mentioned have focused on establishing a direct local link between UAVs' network communication without centralization in ground-based stations (GBS), my work involves providing assistance UAVs to in various scenarios [10].

According to a forecast by the International Telecommunication Union (ITU), network traffic will expand to 5016 Exabytes per month by 2030. In addition, the number of global mobile subscribers will increase to 13.8 billion by 2025 and 17.1 billion by 2030 [11].

Consequently, essential technologies are required to handle the vast amounts of data yielded from smart devices and apps create. Figure 1.1 shows the development cycle of mobile telecommunication technologies every ten years. In this figure, the development from the first generation (1G) to the expected sixth generation (6G) illustrates the data rate and system capacity with service improvement. Unfortunately, natural disasters still challenge targeted services and affect mobile telecommunication throughput. Therefore, disaster management strategies are critical to minimize the degradation risk of wireless communication services. Hence, the disaster management cycle is a continuous process that involves four stages: preparedness, mitigation, response, and recovery.

Preparedness refers to activities undertaken before a disaster occurs to ensure that emergency responders and the public are ready to deal with the consequences of a disaster. This may include developing emergency plans, conducting drills and exercises, and identifying and stockpiling essential supplies.

Mitigation involves efforts to reduce the likelihood and impact of a disaster. This can include improving infrastructure, implementing early warning systems, and enforcing building codes.

Response refers to the actions taken during and immediately after a disaster to protect lives and property. This may involve search and rescue operations, evacuation, emergency medical care and supplies.

Recovery involves activities undertaken after the immediate emergency response to restore normalcy and rebuild communities. This may include debris removal, repairing and reconstructing damaged infrastructure, and assisting those affected by the disaster. Together, these four stages form a continuous cycle of disaster management, where lessons learned from past disasters are used to improve preparedness, mitigation, response, and recovery efforts for future disasters.

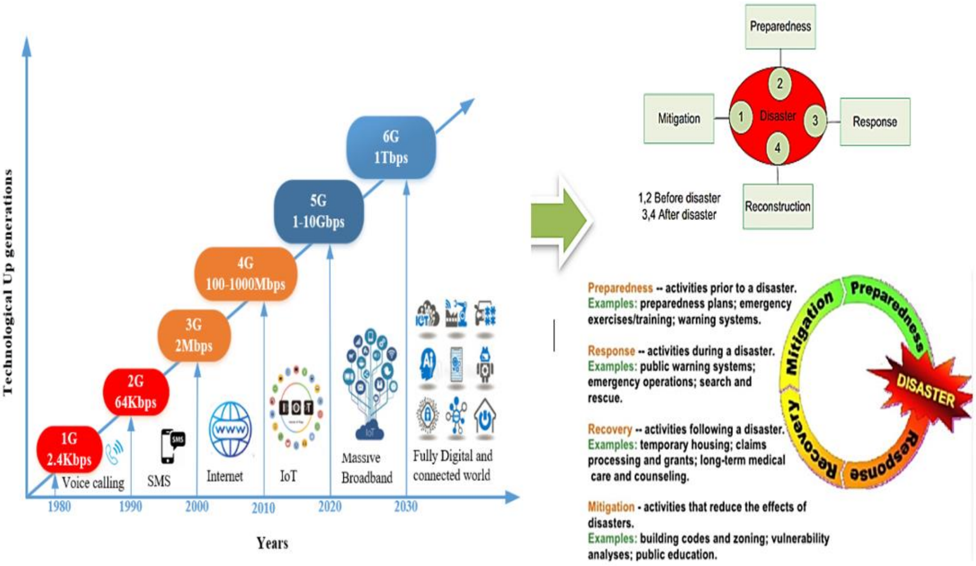


Figure 1.1. Mobile communication development and Disaster management strategies

In this context, the deployment of multi-UAV communication is a promising solution to increase the system throughput through the number of channels added to the network and energy efficiency management [12].

Furthermore, natural disaster event enables public safety and natural security network. On the other hand, the multi-UAV relay hops are critical to guarantee communication between the functional and dysfunctional areas (secured and disaster areas) [13].

To extend the range of coverage and ensure reliable communication in disaster situations, researchers are exploring multi-UAV techniques for exchanging data beyond the coverage area, including multi-hop UAV relay communications [14].

These techniques have shown promise in facilitating fast and effective communication recovery in disaster scenarios [15].

A multi-UAV relay cooperative is essential to improve coverage without a dense infrastructure deployment in disaster areas [16]. This includes the capability to exchange information and provide better coverage service in disaster areas by efficiently using the multi-UAV as relays to serve disaster areas. Effective networking and computing infrastructure would be required with the entire profits of offering low latency and fast response in emergency disaster events using ad-hoc UAV technologies [17]. Therefore, emergencies can generate partial coverage scenarios. Emergency communications have become so important for public safety that it is crucial to address this issue by expanding the coverage area of a cellular system still functioning in an active area [18]. In other words, Public safety and emergency communications have become increasingly important, and ensuring communications with an acceptable Quality of Service (QoS) has become a significant concern [19].

However, synthesizing improved Energy Efficiency in disaster recovery remains a considerable challenge, such as barriers and future work. Therefore, this study provides an alternative solution to cellular networks through UAV cooperatives scheme in the case of infrastructure damage due to natural disasters.

1.2. PROBLEM STATEMENT

Most existing research has focused on wireless cooperative schemes to increase channel capacity for service applications. However, natural disasters can damage all infrastructure networks. In such cases, using unmanned aerial vehicles (UAVs) efficiently can be a potential solution for fast communication recovery in the disaster area. Most current UAV-based solutions employ non-cooperative communication schemes. However, a few recent works on UAV cooperative networks have emerged.

The problem addressed in this research is the limitations of current designs for UAV collaborative networks to recover communication performance in the aftermath of natural disasters. Additionally, existing methods suffer from limitations in system connectivity and efficient performance, as well as consuming high power and negatively impacting the lifetime of aerial vehicles. This study addresses these limitations by proposing a multi-hop ad-hoc network that leverages increasing UAVs to ensure information delivery with system reliable connectivity design with high partner selection and power-saving techniques.

1.3. RESEARCH AIM AND OBJECTIVES

This research explores wireless cooperative schemes with unmanned aerial vehicles (UAVs) to provide safe wireless coverage services in case of cellular network damage caused by natural disasters. The study aims to investigate the feasibility and effectiveness of a multi-UAV cooperative system for disaster recovery, which can guarantee communication between functional and dysfunctional areas, provide alternative access to cellular networks, and increase the system's capacity and energy efficiency.

The objectives of this study are:

- To investigate the existing multi-UAV ad-hoc cooperation relays in next-generation wireless systems for disaster recovery.
- To propose a multi-UAV cooperative system model based on multi-hop connectivity to improve spectral/energy efficiency and capacity for wireless communication in disaster zones.
- To evaluate the performance of the multi-hop UAV cooperative network for fast disaster recovery in terms of system capacity, energy efficiency, and communication reliability.

1.4. RESEARCH SCOPE

The research scope addresses the challenges of establishing reliable and efficient wireless communication in disaster zones. Specifically, the study aims to overcome the vulnerability of telecommunication infrastructures during natural disasters that can hinder the communication abilities of first responders.

The proposed solution involves utilizing UAVs with various communication technologies for quick deployment, flexibility, and connectivity, even in remote areas.

The research also emphasizes multi-UAV communication's importance in improving energy efficiency, capacity, and spectrum efficiency. By establishing communication services for ad-hoc networks without centralized networking, the proposed models for cooperative UAV relay in wireless communication show promising results for enhancing wireless communication in disaster areas. This, in turn, enhances the ability of public safety networks to respond to emergency calls and share critical information during natural disasters.

The proposed system not only aids in rescue operations by connecting people in affected areas but also enables communication with first responders. The study highlights the significance of disaster management strategies and public safety and emergency communications to ensure effective disaster recovery. Additionally, the research delves into managing resources during a disaster event using multi-hop U2U communication, providing valuable insights into the effectiveness of this approach in optimizing communication networks and ensuring effective disaster recovery.

Overall, the study aims to contribute to disaster management and public safety by improving wireless communication capabilities in disaster zones, enabling efficient communication between affected individuals and first responders, and facilitating effective disaster recovery efforts.

1.5. SUMMARY

This study explores wireless cooperative schemes with unmanned aerial vehicles (UAVs) to establish communication between the source and destination in a cellular system and ad-hoc network. The analysis assumes that a Global Base Station (GBS) has been established in the active area of the cellular system, also known as the functional area. However, the UAVs in the inactive region, outside of the cellular coverage system, are referred to as the dysfunctional area.

To address this challenge, the study proposed a model of cooperative UAV communications where user equipment can communicate through intermediate relays. The study's objective is to analyze signaling to enable communications in dysfunctional areas. This research aims to provide alternative access to cellular networks in infrastructure-damaged areas caused by natural disasters.

The proposed solution involves designing a multi-UAV relay scheme for recovering wireless communication in a disaster scenario. This approach explores the extent of UAV collaboration to increase spectral/energy efficiency and capacity and provide wireless communications in the disaster zone. The study intends to evaluate the performance of the multi-hop UAV cooperative network for fast disaster recovery, focusing on system capacity, energy efficiency, and communication reliability.

1.6. REPORT OUTLINE

This report consists of five chapters. Chapter 1 provides an overview of wireless technologies affected by natural disasters, the problem statement, the research aims and objectives, the research scope, and a summary. Chapter 2 reviews the state-of-the-art of natural disaster effects on wireless networks that support the cellular system and their role in disaster communication relief. The chapter discusses the cooperation of UAVs to improve coverage areas with wireless enabling technologies and emphasizes the critical requirements for natural disaster communication relief.

Ultimately, the cooperation of UAVs and wireless enabling technologies enhances the safety and security of individuals impacted by natural disasters by enabling effective communication and response efforts. Furthermore, a gap analysis analyses the methods and techniques used to improve post-disaster communications of the chosen wireless network standard.

Chapter 3 describes the system modelling and algorithms for the network scenario of the system model and method flowchart standard that satisfies the minimum requirements to recover disaster communications. The chapter proposes cooperative UAV scenarios and system models for fast disaster recovery. Additionally, this chapter describes the main equations related to this system modelling and parameter configuration in the simulation model for each research contribution and system parameters for every stage.

Chapter 4 focuses on the research on the achievable performance of efficient resource management using the first partner performance of UAVs cooperative for saving power. The chapter provides an analysis of the performance of single and multi-UAVs.

Chapter 5 presents the overall conclusion of the research work and the possibility of the research's impact on future technology. Finally, this chapter mentions the current limitations of the proposed work and gives direction for further improvement in the future.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a brief overview of the impact of natural disasters on network infrastructure and the available solutions for ensuring reliable connectivity between UAVs. Network infrastructure failure during a disaster is often due to the inability of ground-based stations to provide wireless services in affected areas. To address this issue, UAV collaboration can be utilized to establish fast connectivity solutions. However, it is essential to note that implementing such solutions can also result in unintended consequences, such as further damage, injury, or loss of life. Thus, the UAV network must work collaboratively to serve as a substitute for terrestrial communication systems in disaster scenarios. However, it is also essential to acknowledge UAVs limitations in processing power consumption and increasing node connectivity. Therefore, an effective disaster recovery design that utilizes UAVs to restore communication systems is necessary. Furthermore, designing multi-UAV collaborations to enhance the efficiency of disaster recovery efforts is crucial in addressing the challenges posed by natural disasters. Figure 2.1 depicts an overview of the entire literature review structure reported in this thesis.

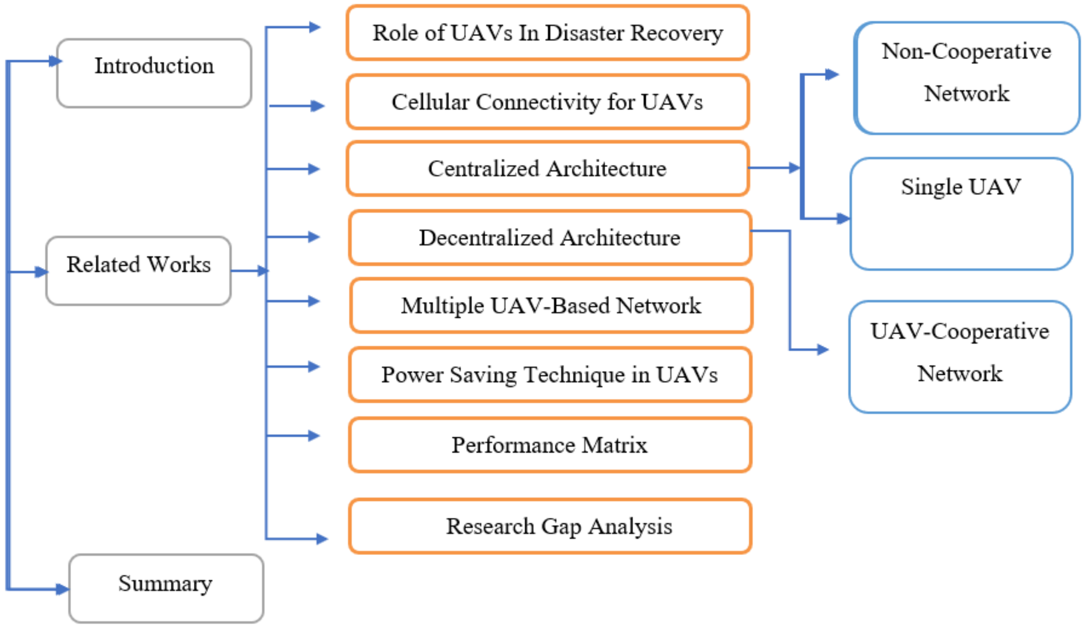


Figure 2.1. The structure of literature review

2.1. INTRODUCTION

Natural disasters are significant adverse events resulting from natural processes on Earth, including tsunamis, earthquakes, floods, volcanic eruptions, avalanches, blizzards, cyclonic storms, hailstorms, tornadoes, fires, pandemics/epidemics, landslides, and other natural events. Natural disasters often cause extensive damage to buildings and infrastructure. Depending on their types and severities, significant loss of life or casualties can occur due to disasters or associated consequences (e.g., fire after an earthquake) [20]. During large-scale natural disasters and unexpected events, the existing terrestrial communication networks can be damaged or destroyed, significantly overloading them, as evidenced by Hurricanes Sandy and Irma [21]. In 2017, hurricanes Harvey, Irma, and Maria in the USA and the earthquake in Central Mexico affected network infrastructure. In other cases, network infrastructures in Italy, Nepal, and New Zealand were affected by earthquakes. The network communication within the disaster zone could not provide wireless coverage services. These cases highlight the necessity for investigating cellular network weaknesses for handling traffic in these crucial circumstances. For natural disaster wireless cooperative schemes, the UAV network must link dysfunctional and functional areas to search and rescue the victims.

2.2. ROLE OF UAVS IN DISASTER RECOVERY

Drones or UAVs have been used as data collectors or relays. Relay transmission systems, such as ad-hoc and multi-hop networks, transfer data to dead communication zones that are unreachable directly [22]. These technologies have attracted interest in recent years for Internet-of-Things sensor networks [23]. Much research on ad-hoc and multi-hop networks has been published. However, radio station installation locations must be considered to minimize barriers, such as buildings and areas with challenging terrain, to implement these traditional technologies on the ground. Furthermore, traditional techniques have several flaws, such as multipath signal interference and the concealed terminal problem [24]. On the other hand, UAVs can travel freely to a location where the effect of topography and buildings may be avoided because the networks are built in the air.

Moreover, combining a UAV and a terrestrial radio station can send information to dead communication zones [25]. Drones, a type of UAV, have become increasingly popular in recent years, and research on relay transmission utilizing multiple drones has progressed [26]. UAVs face many challenges related to the assigned tasks as relays, such as bandwidth and power consumption. Additionally, single or non-cooperative UAVs may share the same issues mentioned in the relay network. To this end, cooperation between UAVs may benefit the network for these problems.

UAVs, serving as data relays, hold significant promise for delivering on-demand connectivity, providing public safety services, or aiding recovery after communication infrastructure failures caused by natural disasters [26]. A UAV-assisted emergency Wi-Fi network can expedite rescue operations and synchronization, and avoid communication disruption to the relief Centre, for better rescue planning and monitoring of natural disaster management [27].

The advantage of UAVs is that they can fly at different altitudes according to their purposes and needs, provide wireless services to ground nodes, and serve as the best alternatives for reinstating communication systems during disasters [28]. UAVs can be used as mobile base stations to provide overall wireless coverage services while minimizing channel access delays in disaster-stricken areas and guiding Search and Rescue (SAR) teams [29]. One such option is the multi-UAV communication design, which extends the wireless coverage area [30]. Furthermore, improving the QoS depends on the line of sight (LoS), received signal strength and bandwidth, system capacity, and delay performance [31].

UAVs integrated with wireless communications must keep communication lines open and running during faulty communication in natural disasters. In disaster recovery, UAVs are classified into single-UAV (non-cooperative) and multi-UAV (cooperative) communications. The link is established with Ground Base Station (GBS) in single-UAV communication. In contrast, multi-UAV communication establishes the link with several UAV nodes that communicate with the GBS. Therefore, a multi-UAV (cooperative and layered) system can take two patterns: UAV to UAV (U2U) and UAV to the ground station (U2G), to provide solutions for energy and coverage range issues for performing the task efficiently [32].

Furthermore, a UAV flight path is classified into o-path, rectangular-path, zigzag-path, and s-path. Meanwhile, the s-path is used for large-scale paths, whereas the o-path, rectangular path, and zigzag path are used for short flight duration with less energy consumption [33]. In this context, the flight time is directly related to the UAV energy consumption limitation, enabling longer hovering times to provide coverage services [34]. Thus, the UAV can be categorized into a fly at a lower altitude platform (LAP) and a higher altitude platform (HAP) to provide the coverage service [35]. Subsequently, the UAVs can function at LAP/HAP to provide an LoS communication link to GBS and streamline emergency responses [36]. Utilizing minimal energy establishes dependable connections over long distances [34]. These flying platforms eliminate some drawbacks of space technology communication for assisting GBS, such as cost, delay, deployment time, flexible mobility, operability, fast networking, and cost-effectiveness. Subsequently, UAV deployment in a LAP plays an efficient role in disaster recovery due to ease of deployment and LoS at low cost [37].

While UAVs suffer from limited battery lifetime due to the standardization and the focus on disaster-resilient communication, this limitation significantly restricts their capabilities [38]. Thus, UAV energy consumption and battery life become significant constraints in the case of network infrastructure collapse [39]. This becomes the primary drawback as UAVs run on battery power, which can run out quickly during disaster coverage services. Therefore, backhaul connectivity, security, and energy consumption are some constraints of these flying platforms. On the other hand, tethering represents a critical solution for providing a power supply to the UAV. Tethering is used to tie the UAV to the ground, speed up data transfer, supply power to the UAV, and solve the battery lifetime [40].

Networked Tethered Flying Platforms (NTFPs) are used by practically every flying platform, including the government, military, and industries, to overcome constraints [33]. However, issues with the ground-based stations (GBS) arise due to their power source limitations during disaster occurrences. Considering this, Unmanned Aerial Vehicles (UAVs) will be integrated as free-flying platforms in 6G architectures and will serve as crucial enablers for developing wireless cooperative communication systems. Therefore, replacing the GBS with a UAV is viable, and it can be integrated with optimal relay hops to improve wireless coverage services. In Japan, UAVs were used for post-disaster communication after the 2011 earthquake and tsunami to relieve cooperative wireless network services [30]. The UAVs served as relay-assisted nodes to transfer wireless information and power GBS outside the coverage area to the core network. However, UAVs have limitations regarding the range of transmission and the strength of the signal to restore communication after a disaster. Thus, A promising method for expanding coverage using Device-to-Device (D2D) is to have an optimal relay communication to improve wireless coverage services during disaster events [34].

A UAV is considered a relay station for reliable connectivity with GBS [35]. In this context, amplifying the signal strength at the relay nodes assists in connecting with nodes outside the coverage area to access coverage services. Furthermore, the UAV can fly and transmit wireless coverage to the GBS. The selection of a relay node within the edge of a UAV's coverage area is determined by evaluating the remaining energy and the connection quality for each potential node. Thus, cooperative wireless communication aims to expand the coverage of unmanned aerial vehicles (UAVs) by using relay points in a wireless communication system that transmits data from the UAVs to the ground. This system operates alongside Ground-Based Stations (GBS) in the same environment.

2.3. CELLULAR CONNECTIVITY FOR UAVS

UAVs have gained remarkable popularity due to their numerous applications in various domains, including surveillance, health, agriculture, and smart cities. They are increasingly used to aid coverage services in disaster management operations, particularly for disaster preparedness and recovery tasks. One of the advantages of UAVs is that they do not require highly constrained and expensive infrastructure, such as cables. They can quickly fly and dynamically change their positions to provide on-demand communications for search and rescue teams in emergencies [36]. Numerous surveys have summarized these advantages for various circumstances and situations [37].

UAVs can be integrated with multi-layered architecture, allowing emergency communications with minimum energy consumption that effectively reach victims in remote areas [38]. UAV-enabled wireless networks offer many benefits, including enhanced coverage area, increased system capacity, low cost, low maintenance, on-demand and swift deployment, high mobility, and high probability of Line of Sight (LoS) [39]. UAVs are also known for their reliability, connectivity, and ability to improve the Quality of Service (QoS) for specific heterogeneous networks [40]. Therefore, UAVs are a promising solution to enhance public safety network scenarios to support mission-critical applications, such as earthquakes, floods, and fires.

However, UAVs have limitations in public safety networks regarding processing energy efficiency and battery power lifetime for cooperative communication. Therefore, various designs could enable communication between UAVs and between UAVs and Ground Control Stations (GCS).

2.4. CENTRALIZED ARCHITECTURE

In a centralized architecture, the GCS serves as the central node of the network, to which all UAVs in the swarm are connected. The UAVs communicate directly with the GCS, exchanging commands, control, and sensitive data. However, the UAVs are not directly connected, and the network is centralized at the GCS. Information is routed through the GCS to facilitate inter-drone communication, which acts as a relay in the communication chain[41]. Furthermore, because the data must pass through a relay, there will be a more significant latency between the drones. Since UAVs must travel long distances to complete their missions, high transmission rates are necessary for communication with the GCS. However, the centralized architecture is not robust, as the GCS is a single point of failure. Therefore, any arising problems will impact the entire network, potentially causing communication disruptions or even a complete loss of connectivity [38].

2.4.1. Non-Cooperative Network

A Non-Cooperative UAV system can only perform limited operational tasks and cover smaller neighbourhoods with a direct network connection. However, selecting a near GCS can provide the network with more efficient and stable route solutions during post-disaster situations [54]. Deploying UAVs with the GCS can reduce outage probability and energy consumption while reducing the computational complexity of network design, potentially saving many lives in natural disaster scenarios. To extend coverage area, minimize energy consumption, and maintain network sustainability, a single UAV can be integrated with D2D communication under GCS connectivity. In a centralized architecture, each UAV has a unique communication channel with the GCS, and direct communication between drones is impossible in this network. However, GCS can act as a relay if such communication is needed [55].

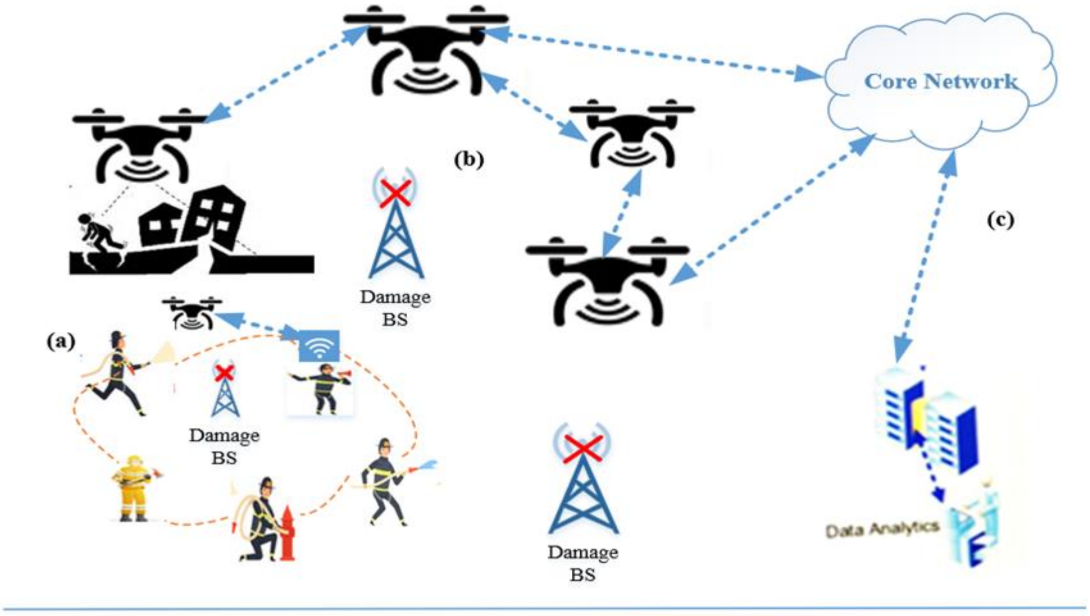
2.4.2. Single UAV-Based Network

The UAV Ad-hoc Network (UAVANET) is designed to improve data transfer between nodes in the network. However, the existence of an end-to-end multi-hop path across

UAVANET depends on the willingness of vehicles to cooperate in data forwarding. A study by the author [54] proposed that vehicles connect with UAVs to enhance end-to-end path connectivity. On the other hand, the author of [42] discusses the challenges posed by non-cooperative UAVs, particularly in low-altitude platforms. A UAV is considered non-cooperative if no relevant information is available. While their controllers handle most non-cooperative and cooperative UAVs, collisions between non-cooperative UAVs and aircraft have become more common, resulting in significant losses.

2.5. DECENTRALIZED ARCHITECTURE

In contrast to the centralized architecture, the decentralized design enables direct or indirect communication between two UAVs. Instead of relying on the GCS to extend coverage with a multi-hop transmission, the information can be routed through a third UAV acting as a relay. The decentralized network is more robust because it does not rely on a single point of failure. A UAV ad-hoc network is an example of a decentralized network, as shown in Figure 2.2. The work in [43] introduced non-centralized UAV communication for multi-layer ad-hoc networks. In [44], the authors used three meta-heuristic optimization algorithms to enhance the efficiency of FANETs by reducing packet dropping rate (PDR) and delay. Simulation results showed that the proposed algorithms improve the quality and reliability of communication.



(a) UAV- SARs Collaborate (b) UAVs Relays (c) Disaster Management and mentoring

Figure 2.2. Multi UAV Ad-hoc Network

2.5.1. UAV Cooperative Network

In the vision of 5G and beyond 5G (B5G), establishing a cooperative UAV network can employ UAVs as relays to improve the coverage and connection of terrestrial users [45]. Drones can move freely to regions where the effects of topography and buildings may be avoided since the networks are established in the air. However, implementing drone-based relay transmission in the air faces two significant challenges. The first is that the relay communication mechanism consumes bandwidth whenever the drone transfers information. As a result, throughput is considerably reduced since several relay stations share the radio channel. The fewest possible relay stations should be used to solve this issue, and direct long-distance transmission is the best method. The second problem develops due to the first problem's resolution because the propagation loss increases when information is transmitted directly over a long distance.

Furthermore, as the frequency of interference from ground waves rises, transmission signal mistakes increase. A transmission strategy that reduces transmission faults is necessary to overcome this problem. Although several research studies on drone communication have been published, most focus on relay mechanisms between drones and ground stations [46]. With an increasing number of UAVs in the sky, it's essential to establish an efficient UAV2UAV communication system to avoid collisions between flying elements [47] and enable them to perform mutual tasks.

Moreover, several works focus on using UAVs as relays. For instance, [48] considered improving the confidentiality rate by assuming a moving UAV for relaying. In [49], the outage probability of a UAV network was analyzed when a single UAV acts as a relay between the ground station and other UAVs. Meanwhile, the authors in [50] studied relaying UAVs in a wireless network in two scenarios: a) multiple-hop single link setting for relaying system using multiple UAVs, b) dual-hop multilink setting for a relaying system using multiple UAVs. The results of numerical calculations show that the multiple dual-hop links option is suitable in air to ground (A2G) channels whose PL parameters are a function of UAV position. Still, when PL parameters are independent of the position of UAVs, the multiple-hop single link is preferred only when the distance from the source to the destination is significant. Andre et al. [51] investigated the applicability of various wireless technologies to support UAV networks compatible with the QoS requirements of different applications in terms of throughput and latency. The authors in [52] discuss the significant achievements in UAV cooperative control and explore many challenges and issues in collaborative UAV networks. Several studies have introduced the topic of low-altitude platforms, such as the challenges of UAV networks [53], the viability of using UAVs in the cellular network [54], [55], and routing challenges in FANET [56]. The author [57] surveyed various protocols and mechanisms for developing UAVs while considering LAP communications, HAP communications, and integrated airborne communication systems. The authors in [58] evaluated the initial characteristics of uplink multiuser multiple input multiple outputs (MU-MIMO) cooperatives that rely on a control scheme for reliable and efficient communication of UAVs. The simulation results reveal that the suggested method achieves throughput 1.5 times better than non-cooperative schemes, and the proposed scheme requires only three stations to achieve acceptable results.

2.6. MULTIPLE UAV-BASED NETWORKS

Multi-UAV collaboration has been evaluated based on average capacity, energy efficiency, line-of-sight probability, path loss, throughput performance, coverage probability analysis, and outage probability performance. Multi-UAV relays can assist Public Safety Networks through wireless power transfer, which is achieved through conventional Power Splitting (PS) and Time switching (TS) strategies to enhance energy harvesting between the source and destination nodes and reduce large-scale fading [59]. Therefore, multi-UAVs collaborate to reach the victims efficiently.

In addition, Shortest Path Routing (SPR) can provide fast connectivity response for UAVs performing operation tasks. Multi-UAVs perform several missions to save energy and lower system latency. The proposed algorithms are designed to prolong the system's lifetime and minimize the system's response to network failure. Furthermore, multi-UAV collaboration algorithms with SPR can enable communication and monitoring of larger areas, allowing for quick response for disaster communication recovery.

In contrast, multi-UAV communication establishes a link between several UAV nodes that communicate with ground user devices. Therefore, a multi-UAV (cooperative and layered) system can take two patterns: UAV to UAV (U2U) and UAV to the ground station (U2G), to provide solutions for energy and coverage range issues for the rescue and safety of victims [60]. In this context, Multiple UAV-based networks can be classified into cooperative and non-cooperative networks.

Table 2.1. Comparison Between Cooperative and Non-Cooperative UAVs

Comparison parameters	Cooperative UAVs	Non-cooperative UAV
Transmission power	Low	High
Power consumption	Low	High
Spectrum Efficiency	High	Low
Network topology	Non-Centralized	Centralized
Cost	High	Low
Probability of failure	Low	High
Security	can be exploited by attackers	More Robust

2.7. POWER SAVING TECHNIQUE IN UAV NETWORKS

Increasing the hovering time of UAVs depends on each UAV's battery bank and power consumption. The assigned mission and environmental factors may increase power consumption, reducing battery lifetime. Researchers have proposed several techniques to save power or improve battery status, such as wireless charging techniques like solar, laser, and power harvesting. For example, the work in [61] investigates energy harvesting for small UAVs from solar sources and vibrations, while the authors in [62] consider deploying UAVs for power efficiency while meeting user demands. The author in [63] proposed a framework for UAV communication based on energy efficiency. In [64], the authors deploy a UAV as a flying base station to improve the capacity and coverage area of the macro cell with minimum power requirements. The authors in [65] discuss the challenges of coordinating a swarm of UAVs to perform critical tasks cooperatively and cooperative localization techniques that can decrease power consumption. Mobile cellular technologies like 4G, 5G, and beyond 5G are expected to mitigate many limitations that currently hinder the viability of UAVs, such as networking challenges, communication range, and power calculation. A study was conducted in [66] on dynamic multi-UAV cooperation to ensure power-efficient aerial communication. The selection of UAVs for the cooperative serving of ground users is made intelligently to reduce UAVs' power consumption. The proposed scheme significantly minimizes the power consumption for each UAV while guaranteeing the quality-of-service requirement. In [67], the authors proposed a tracking algorithm in non-cooperative UAVs based on three zones. They calculated the energy consumption caused by transmitting images through UAVs' horizontal and vertical movement. Simulation results showed that the movement's energy consumption is higher than that consumed for communication. Meanwhile, the authors in [68] proposed a cooperative relaying scheme to extend network lifetime using a suboptimal algorithm for energy efficiency.

2.8. PERFORMANCE MATRIX

Cooperative sensing and communication via UAVs are necessary for post-disaster communication scenarios, and integrating UAVs with wireless sensing networks can improve the quality of their services. FANETs with an adaptive energy-efficient scheme are crucial for achieving specific network requirements in a post-disaster communication scenario [69]. UAV relays play a significant role in achieving a higher achievable rate via multi-access channels using Air-to-Air communications and resolving relay power constraints [70]. Therefore, performance metrics that automatically evaluate the current UAV technology are necessary to improve the quality of services, planning, and monitoring skills for multi-environment connections [71]. Integrating UAVs with wireless sensing networks is a promising technique for monitoring environmental parameters and accomplishing data collection tasks [72]. Hence, the performance of UAVs in flying ad-hoc networks (FANETs) with an adaptive energy-efficient scheme has become crucial to achieving specific network requirements [73].

2.9. RESEARCH GAP ANALYSIS

Table 2.2. Comparison of Existing Works (a-Single-UAV, b- multi-UAV c- Post-Disaster Recovery, d- Energy efficiency, e- Coverage improvement)

References, Year	Highlighted	a	b	c	d	e
[28] , (2019)	In disaster recovery efforts, a smartphone can act as a relay for nearby devices in a Wi-Fi network supported by a base station (BS). This arrangement facilitates communication between neighboring devices, enhancing rescue operations' effectiveness.	✗	✗	√	✗	√
[74] , (2022)	This summarizes a plan to address significant disasters by restoring ground-based communication infrastructure. Using a multi-hop approach, the strategy establishes communication links between areas affected by the disaster and those unaffected.	✗	✗	✗	✗	√
[75], (2022)	UAV technology is proposed to provide coverage services and help	√	✗	√	✗	√

	SAR teams to achieve their operations tasks.					
[76] , (2020)	A Tethered UAV is currently utilized to assist in the restoration of the cellular network following a disaster.	√	χ	√	χ	√
[77] , (2021)	In the event of a disaster, where network congestion, partial functionality, or complete isolation occurs, D2D, UAV-assisted communication, and mobile ad hoc networks are suggested as potential solutions for post-disaster recovery.	√	√	√	χ	χ
[78],(2018)	The author proposed cooperative control between multi-UAVs to enhance the effectiveness of a disaster recovery mission.	√	√	√	χ	√
[79] ,(2017)	The utilization of multi-hop D2D communication can result in improved energy efficiency and spectral efficiency, thereby extending the coverage range of cellular network techniques.	χ	χ	√	√	√
This work	The primary focus of this study is to design and investigate the potential of multi-UAV wireless cooperative schemes for next-generation disaster recovery, which can improve coverage area, spectral efficiency, and energy efficiency in disaster zones. To achieve this aim, the study has set three specific objectives. Firstly, the study aims to investigate the existing multi-UAV ad-hoc cooperation relays in next-generation wireless systems for disaster recovery. This objective involves a comprehensive review and analysis of current research and practices related to multi-UAV cooperation relays, including their benefits, limitations, and challenges. Secondly, the study aims to propose a multi-UAV cooperative system model	√	√	√	√	√

	based on multi-hop connectivity to improve spectral/energy efficiency and capacity for providing wireless communication in disaster zones. This objective involves developing a comprehensive model that considers the characteristics of disaster scenarios, such as infrastructure damage, lack of power supply, and unpredictable environmental conditions. The proposed model should consider the multi-hop connectivity among UAVs, which can increase network capacity and reduce transmission power consumption. Finally, the study aims to evaluate the performance of the multi-hop UAV cooperative network for fast disaster recovery in terms of system capacity, energy efficiency, and communication reliability. This objective involves conducting extensive simulations and experiments to validate the proposed model and measure the system performance under various disaster scenarios. The results of this objective can help identify the strengths and weaknesses of the proposed multi-UAV cooperative system and provide insights for future improvement. Overall, this study can contribute to developing more efficient and reliable wireless communication systems for disaster recovery using multi-UAV cooperative schemes.	

2.10. SUMMARY

This study uses a UAV network relay with a wireless cooperative scheme to establish communications in functional and dysfunctional areas during natural disasters. The relay node acts as a hub to send and receive signals between areas with coverage and those without. The project aims to enhance the network's capacity and power-saving using a UAV network cooperative architecture that employs relay-assisted transmission. The study aims to improve energy efficiency to minimize power consumption and to arrange communication between ad hoc UAV network relays to cover natural disasters.

To alert and communicate with civilians during disasters, operational commercial communications infrastructure and resources must be utilized. While existing technologies use ad hoc communication networks through Wi-Fi Direct, there is little evidence linking natural disasters with single and multi-UAV cooperative communications. The project aims to review prior studies on non-cooperative and cooperative UAV communications as a solution for public safety networks during natural disasters. The goal is identifying connections between functional and non-functional areas to enable reliable channel communication. There has been renewed interest in enhancing capacity, power efficacy, and proximity services through an assisted network, reducing complexity and reliance on the core network. Early research on UAV network communication faced significant challenges in creating link access and establishing direct communication among users without centralizing the core network. This research aims to address these challenges using new techniques.

CHAPTER 3

METHODOLOGY

This section presents the proposed model for a cooperative UAV relay in wireless communication, which aims to provide an efficient network recovery solution during natural disasters. This is an integrated development part that complements the theoretical aspect of the project to achieve the project's aims and objectives. The proposed model, as shown in Figures 3.1 and 3.2, is advantageous because it enables the design of a recovery model that can be implemented with new developments. The proposed model addresses the issue of linking coverage and non-coverage areas (disaster and non-disaster areas) using cooperative UAVs that exchange wireless services provided by the relay. Once the relay node (R_i) is confirmed, the system can transmit a radio signal (Rs) into non-functional areas through ad-hoc networks. This UAV relaying node increases the system’s capacity, energy, and spectrum efficiency while reducing the relay host's transmission power and extending the system's coverage area. Subsequently, the UAV receives signals through relay hops from the source to the destination. It then connects with the BS_1 in the coverage area as the source and starts transmitting signals to its neighboring UAVs to reach the BS_2 in the destination nodes. However, UAVs must ensure that their transmissions do not cause interference that may lead to the failure of the cellular link. This is because interference may arise from spectrum sharing between cellular networks and UAV network scenarios, where there is a different performance of the signal-to-interference-plus-noise ratio (SINR) at the receiver nodes.

3.1. SYSTEM MODEL

The proposed model in Figure 3.1 shows the signal transfer process between the coverage and out-of-coverage areas (disaster areas) through a relay and cooperative communication among UAVs.

The relay node, located on the edge of the active coverage area of BS_1, receives the wireless coverage signal and relays it to the UAVs in the out-of-coverage area. The UAVs in the out-of-coverage area then establish a communication link using multi-UAV communication. It is important to note that the UAVs must have residual energy more significant than the threshold level to participate in the communication link. This is necessary to ensure that the UAV_s have sufficient power to perform their communication tasks and to avoid unnecessary drain on their energy resources. Once the communication link is established, the UAVs can start relaying the signals to each other, effectively creating a multi-hop communication network.

Using a relay node and cooperative communication among UAVs in this model provides several benefits. First, it increases the system capacity, energy, and spectrum efficiency by reducing the relay host's transmission power and extending the system's coverage area. Second, it allows for faster and more efficient communication in disaster areas where the traditional communication infrastructure may be damaged or non-functional. Finally, it helps to ensure that the transmission of signals does not cause interference with the cellular network, which can lead to the failure of the cellular link.

This model presents a promising approach to improving wireless communication through UAVs and cooperative communication in disaster areas. By establishing a reliable communication link between the coverage and the out-of-coverage regions, it has the potential to significantly enhance the ability of public safety networks to respond to emergency calls and share critical information during natural disasters.

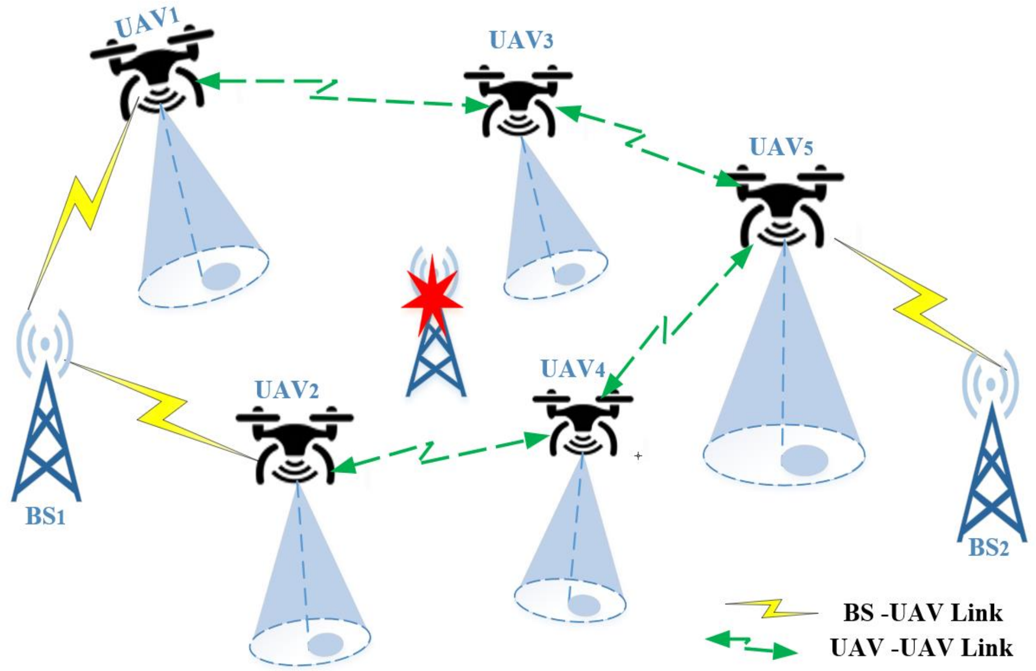


Figure 3.1. Network Scenario of System

The channel between UAVs and ground base stations (i.e., BS_1, BS_2) in the downlink are characterized as A2G channel links. The gain of channel link from UAVs to the BSs for Line of Sight (LoS) and Non-Line of Sight (NLoS) is given by[79] , [80].

$$h_{(s,d)-r} = \sqrt{(h^2 + x^2 + y^2)^{-\alpha}} \qquad \text{For LoS} \tag{3.1}$$

$$h_{(s,d)-r} = \eta\sqrt{(h^2 + x^2 + y^2)^{-\alpha}} \qquad \text{For NLoS} \tag{3.2}$$

Where;

$h_{(s,d)-r}$: is the channel gain between the source nodes (BS_1) to relay and the channel gain from relay destination nodes (BS_2).

h are the UAV's altitudes (x, y) is the source and destination nodes coordinated in 2D and UAVs relay nodes coordinates in 3D.

α : Pathloss exponent.

η : is excess loss encountered for non-line of sight links from UAVs and ground nodes. The probability of a Line of sight (P(LoS)) link represents as a function of ground nodes' elevation angle θ and environment parameters a, b such that LoS probability associated with ground nodes can be shown as follows;

$$P_{LoS} = \frac{1}{1+a\,exp(-b(\theta-a))} \tag{3.3}$$

Where θ is elevation angel, and it is calculated as:

$$\theta = \frac{180}{\pi} sin^{-1}\left(\frac{H}{\sqrt{x^2+y^2+h^2}}\right) \tag{3.4}$$

The Non-Line of Sight (NLoS) probability of the ground nodes *can* be obtained as follows:

$$P_{NLoS} = 1 - \left(\frac{1}{1+a\,exp\big(-b(\theta-a)\big)}\right) \tag{3.5}$$

Then the SINR at the i_1 relay nodes are denoted as follows:

$$SINR_{i_1} = \frac{p_s\left|h_{sri_1}\right|^2}{p_{I_{i_2}}\left|h_{I_{i_2}}\right|^2+\sigma_{sr}^2} \tag{3.6}$$

Where;

p_S : denotes the source BS1 transmission power.

h_{sri_1}: Attenuation from the sources base station to the i_1 relay nodes

$p_{I_{i_2}}$: The interference power from i_2 relay nodes

h_{Ii_2} : Attenuation from the i_2 relay nodes

σ_{sr}^2 : The source-relay Background noise

Hence, to calculate the SINR at the i_2 relay nodes denoted as follows:

$$SINR_{i_2} = \frac{p_{i_1}|h_{ri_2}|^2}{p_{I_{i_1}}\left|h_{I_{i_1}}\right|^2 + \sigma_{ri_1}^2} \tag{3.7}$$

Where;

$\sigma_{ri_1}^2$: The i_1 relay nodes' Background noise

Finally, calculate the SINR at the i_3 relay nodes denoted as follows:

$$SINR_{i_3} = \frac{p_{i_2}|h_{ri_3}|^2}{p_{I_{i_2}}\left|h_{I_{i_2}}\right|^2 + \sigma_{ri_2}^2} \tag{3.8}$$

Where;

$\sigma_{ri_2}^2$: The i_2 relay nodes' Background noise

Then the capacity of the i_1 relay nodes are denoted as follows:

$$C_{i_1} = log_2\left(1 + \frac{p_s|h_{sri_1}|^2}{p_{I_{i_2}}\left|h_{I_{i_2}}\right|^2 + \sigma_{sr}^2}\right) \tag{3.9}$$

Hence, to calculate the capacity of the i_2 relay nodes denoted as follows:

$$C_{i_2} = log_2\left(1 + \frac{p_{i_1}|h_{ri_2}|^2}{p_{I_{i_1}}\left|h_{I_{i_1}}\right|^2 + \sigma_{ri_1}^2}\right) \tag{3.10}$$

Furthermore, to calculate the capacity of the i_3 relay nodes denoted as follows:

$$C_{i_3} = log_2\left(1 + \frac{p_{i_2}|h_{ri_3}|^2}{p_{I_{i_2}}\left|h_{I_{i_2}}\right|^2 + \sigma_{ri_2}^2}\right) \tag{3.11}$$

3.2. PARTNER SELECTION METHOD

The network utilization can be leveraged by minimizing h_{sri_1}, h_{ri_2} and h_{ri_3} Therefore, the first selection criteria (SC$_1$) is set as follows [83] :

$$SC_1 = arg \min_{sri_1 \in R} \left(\frac{1}{h_{sri_1}} \right) \tag{3.12}$$

The second selection criteria (SC$_2$) is set as follows:

$$SC_2 = arg \min_{ri_2 \in R} \left(\frac{1}{h_{ri_2}} \right) \tag{3.13}$$

The third selection criteria (SC$_3$) is set as follows:

$$SC_3 = arg \min_{ri_3 \in R} \left(\frac{1}{h_{ri_3}} \right) \tag{3.14}$$

The energy efficiency is calculated by:

$$EE_i = \frac{C_i}{p_i} \tag{3.15}$$

The spectrum efficiency is calculated by:

$$SE_i = \frac{C_i}{B_1} \tag{3.16}$$

Where B : represents the bandwidth communications.

3.3. NETWORK CONFIGURATION

To establish the communication between the functional and dysfunctional areas during natural disasters, it is assumed that a scenario of a UAVs wireless cooperative network underlying a cellular network where R$_i$ intends to communicate with active BS$_{1 \text{ in source}}$

and $BS_{2\ \text{in distention}}$. According to figure 3.3, the UAVs are hovering in the dysfunctional area. Therefore, the BS_1 sends the acknowledged messages to the UAVs relay (UAV_{Ri}) to know the number of UAVs that need to be connected. After that, the BS_1 handles the home location register (HLR) and visitor location register (VLR) to the first UAV s relays (UAV_{Ri}). Subsequently, the ad hoc network of the UAVs in the disaster area communicates with each other by Partner Selection Method (PSM). First, the (UAV_{Ri}) node near the BS_1 is selected based on the higher ($SINR_{Ri}$). Then, the UAVs relay hopes are selected for those nodes when the node's residence energy exceeds the threshold. After that, UAVs established the communication links for hops (1&2) based on the partner selection method for $SINR_{Ri}$. In those cases, they calculate the capacity of the first partner selection based on (CS_1, CS_2) and CS_3, respectively. Finlay, we calculate the energy efficiency and spectrum efficiency to measure the performance of network energy consumption improvement. This study uses MATLAB to analyze the impact of several (UAV_{Ri}) relay distances on ($SINR_{Ri}$), (C_{Ri}), (EE_{Ri}), and (SE_{Ri}). It files from its memory without any transmission or a helper through a first one-hop U2U transmission or the BS_1 through the edge cell ad0hoc UAV. Hence, the second hop gets the wireless signals from the first hop until the UAVs hover to cover all the disaster areas [84].

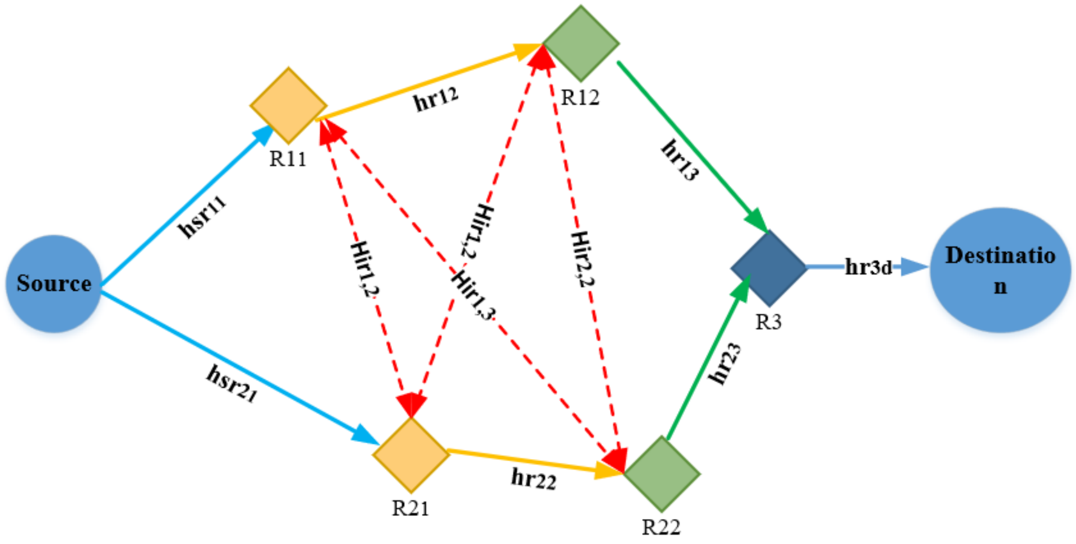


Figure 3.2. UAVs Wireless Relay Network

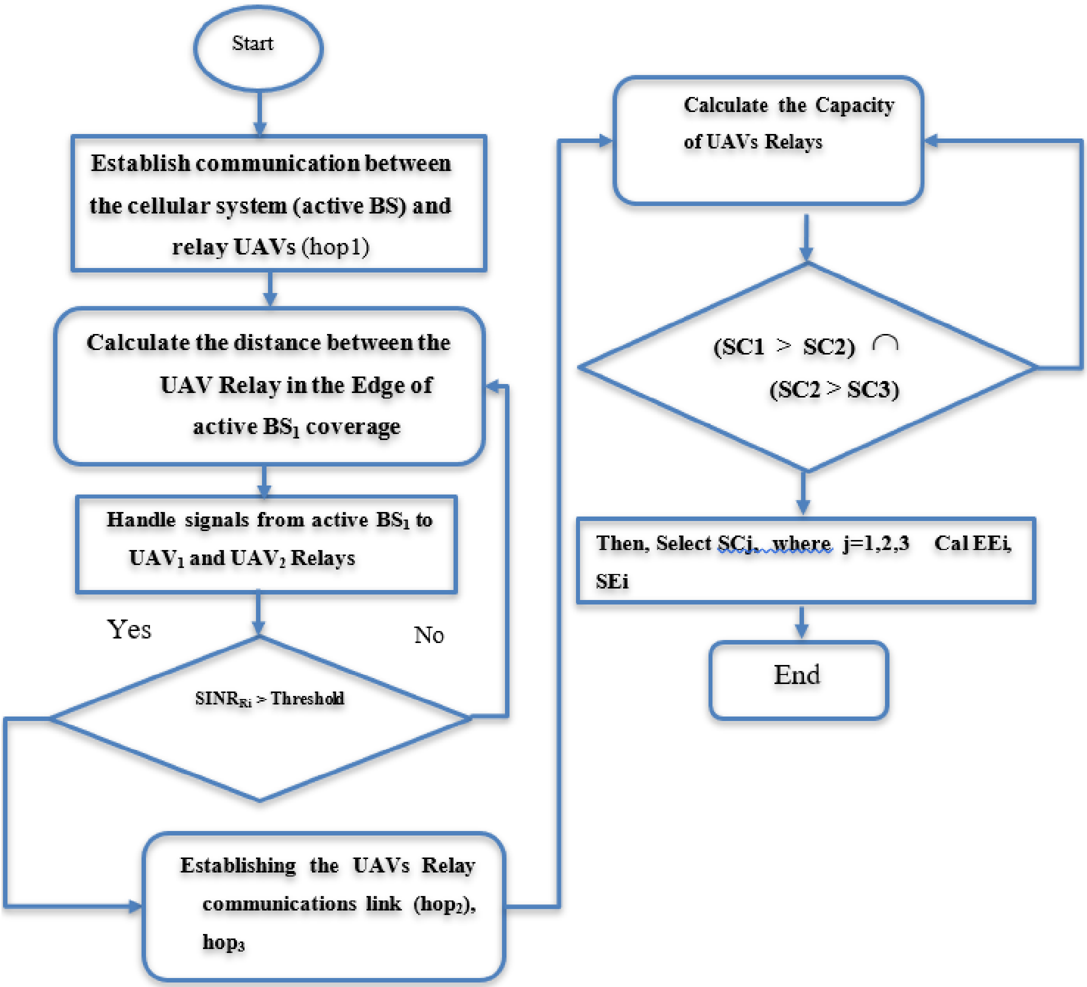


Figure 3.3. Methodology Flowchart for selecting criterion

The deliverables and expected outputs of the research study are from the research work on U2U communications. The outcomes are stated as a milestone research plan. However, the redevelopment of the U2U algorithm will be achievable in the MATLAB code simulation. This context will provide deadlines for achieving the objective, including each viable capacity, spectral efficiency, and energy efficiency to estimate the number of hops.

3.4. U2U COMMUNICATION METHOD

The (U2U) communications are promising techniques to recover disaster communication. The edge user scheme is proposed to develop computation offloading based on U2U communications. This idea is effective in computation execution where

UAVs could offload their computation-intensive tasks to appropriate nearby UAVs where necessary, with the help of the base station. Edge UAVs are a go-between cellular singles (coverage area) and an ad hoc (disaster area) in the dysfunctional area. Therefore, this study considers the U2U relay hops essential to improve cell-edge performance without a dense infrastructure deployment. This contributes to exchanges with the multi-cluster scenario to introduce efficient communication in disaster recovery. In addition, it will be necessary to provide efficient networking and computing infrastructure to support low latency and fast response in emergency disaster events [85]. During emergencies, it is common for communication networks only to provide partial coverage. Given the importance of emergency communication in ensuring public safety, it is necessary to address this issue by expanding the active coverage area. The U2U communications relay might make up a viable solution to this problem.

To put it differently, ensuring public safety and emergency communication has become crucial and ensuring communication that meets an acceptable quality of service standard is a significant challenge. However, to operate as a relay, the relaying concept for the unmanned aerial vehicle (UAV) must be selected from a functional area, assuming that the optimal relaying node has been identified. Hence, the UAVs in the disaster area use the multi-hop U2U to exchange the wireless services the relay provides. Once the relay node (R_i) is confirmed, the system can transmit a radio signal (Rs) into the non-functional areas. UAV_1 receiving Received singles can now be connected with BS1 of the functional area and send alerts to its neighbor UAVs. This relaying node increases the system’s capacity, reduces the transmission power for the UAV relays, and extends the system coverage area. Subsequently, the UAV_1 receives the signals through relay hops, and it can now be connected with the BS_1 located in the functional area and start transmitting signals to its neighbors’ UAVs and so on. The relying helps the network increase capacity, reduce the BS_1 load, reduce the UAV transmission power, and extend the system coverage area. In this scenario, UAV-to-UAV (U2U) communication must avoid causing interference that could result in the cellular link failing. An example of spectrum sharing between cellular and user systems in the network scenario of system model Figures 3.1 to Hence, the second and third hops get the wireless signals from the first hop until the disaster area is covered.

Furthermore, the deliverables and expected outputs of the research study are the deliverables from the research work on U2U relay s communications. The outputs are stated as a milestone research plan. However, the redevelopment of the U2U cooperative algorithm will be achievable in the MATLAB code simulation. In this context, it will provide deadline datasets for achieving the plan, including each viable capacity, spectral efficiency, and energy efficiency, to estimate the number of hops. Table 3.1 shows the simulation parameters for analyzing the environment of disaster recovery where multi-hop U2U communication is considered. Since the active BS_1 is a ware of every channel status in the disaster area through the relay R_i, it will be capable of determining which users can be partnered with distant users in disaster areas. The values in Table 3.1 are the main characteristics of the established multi-hop U2U communication network.

Table 3.1. Simulation Parameters

Simulation Parameters	**Value**
Scenario	Multi UAVs-assisted cellular network
Frequency	2.4 GHz
Modulation	Polar Modulation
BS-power transmit	p_s= 5 w
UAV Relay$_1$-power transmit	p_{i_1}= 2.5 w
UAV Relay$_2$-power transmit	p_{i_2} = 2 w
BS-Antenna design	3-sector, HPBW =48°, Down tilt=3.7°
λ_c **Cellular spatial density**	1×10^{-5}
λ_u **U2U spatial density**	3.3×10^{-4}
U2U transmit distance	100 m
Base station coverage	$1\ km$^2
Bandwidths (B)	B_1= 5 MHz,B_2=10MHz ,B_3=20 MHz
Pathloss exponent	α = 2, 2.5, 3.

CHAOTER 4

RESULTS AND DISCUSSIONS

The results found that the distance, power, and path loss of UAVs affects the performance of wireless signals in different locations. The goal is to transfer the wireless signal from the functional area to the dysfunctional site through multi-UAV cooperative nodes. The simulation parameters and results showed that the parameters affect the performance of SINR transfers based on the first partner selections. Therefore, increasing the capacity of the UAV ad-hoc network will help with fast communication and reduce congested signals between the source (BS_1) and destination nodes (BS_2) during a disaster event.

Moreover, increasing the spectral efficiency of the UAV ad-hoc network will create more communication opportunities and increase the number of channels that can communicate between the coverage and out-of-coverage areas more efficiently. Therefore, capacity will positively affect spectral efficiency and play an essential role in fast recovery communication during disaster events. Additionally, solving the problem of communication latency is crucial in rescuing people's lives.

4.1. SIMULATION RESULTS

The simulation results in this section show how efficiently resources can be managed during a disaster event using multi-hop U2U communications. The primary goal of these communications is to recover communication between the functional and dysfunctional areas following the disaster. The simulation results demonstrate how different parameters, such as UAV distance, power, and path loss, affect the performance of wireless signals in various locations. Analyzing these results makes it easier to determine which nodes can perform the best first paternal selection in the area. This selection is crucial in establishing a reliable communication network that efficiently transmits signals between the affected areas.

Overall, the simulation results provide insights into the effectiveness of multi-hop U2U communications in managing resources during a disaster event. The results can be used to optimize communication networks and ensure that critical resources are allocated effectively to facilitate effective disaster recovery. Figure 4.1 illustrates the distribution of UAVs and BSs in an air-to-air communication scenario. The UAVs, specifically UAV_1 (far from BS1), UAV_2 (Near BS_1), UAV_3, UAV_4, and UAV_5 (Near BS2), are depicted in the air, while the BSs, referred to as BS_1 and BS_2, are located in the ground nodes.

This distribution is significant as it represents the arrangement of UAVs and BSs in establishing a reliable communication network. The presence of UAVs in the air enables communication links between them and ground-based BSs. These UAVs act as mobile communication relays, extending the coverage and connectivity of the network. The system can achieve better coverage and connectivity by strategically placing the UAVs in specific locations and coordinating their communication with ground-based BSs. This distribution pattern allows for effective data transmission, information sharing, and coordination between the UAVs and the BSs.

Figure 4.1 showcases the spatial arrangement and connectivity between the UAVs and BSs in an air-to-air communication setup. It highlights the importance of this distribution for establishing a reliable communication network, which is crucial in various applications such as disaster management, surveillance, and remote sensing.

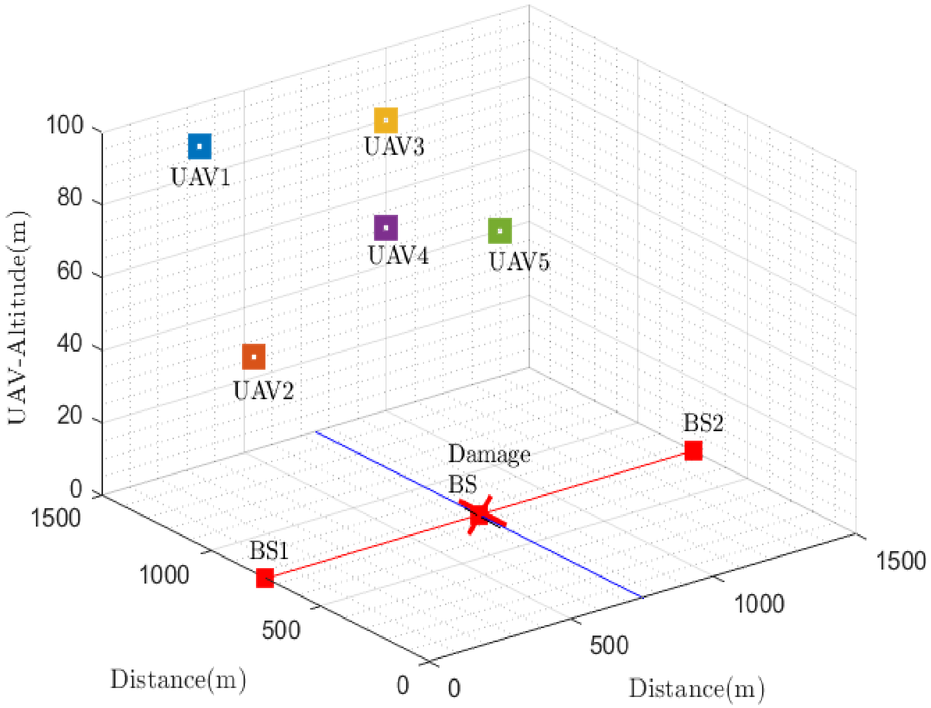


Figure 4.1. Distribution of the UAVs with BSs.

4.2. ANALYSIS OF PERFORMANCE IN HOP$_1$ (BS$_1$ TO UAV RELAY)

Figure 4.2 shows the probability of line of sight (PLoS) versus the distance between active BS$_1$ and the UAV relay links to UAV1 and UAV2. The graph shows two lines representing the P_{LOS} values for two different UAV relay links, namely UAV1 and UAV2. As the distance increases, the P_{LOS} values decrease for both UAV relay links. This means that the likelihood of a direct line of sight between the active BS$_1$ and the UAV relay decreases with increased distance. The P_{LOS} values for UAV1 and UAV2 differ at different lengths. At a distance of 200 meters, the P_{LOS} value for UAV1 is approximately 0.6, while the PLoS value for UAV2 is almost 0.2. At a distance of 300 meters, the PLoS value for UAV1 drops to around 0.3, while the PLoS value for UAV$_2$ drops to approximately 0.1. This graph shows the importance of considering the distance between active BS$_1$ and UAV relay links when establishing a communication network during a disaster. The results suggest that UAV1 may be better for establishing communication with active BS1. Overall, this graph provides insights into the impact of distance on PLoS values between active BS$_1$ and UAV relay links, which can be used to optimize communication networks and ensure effective disaster recovery.

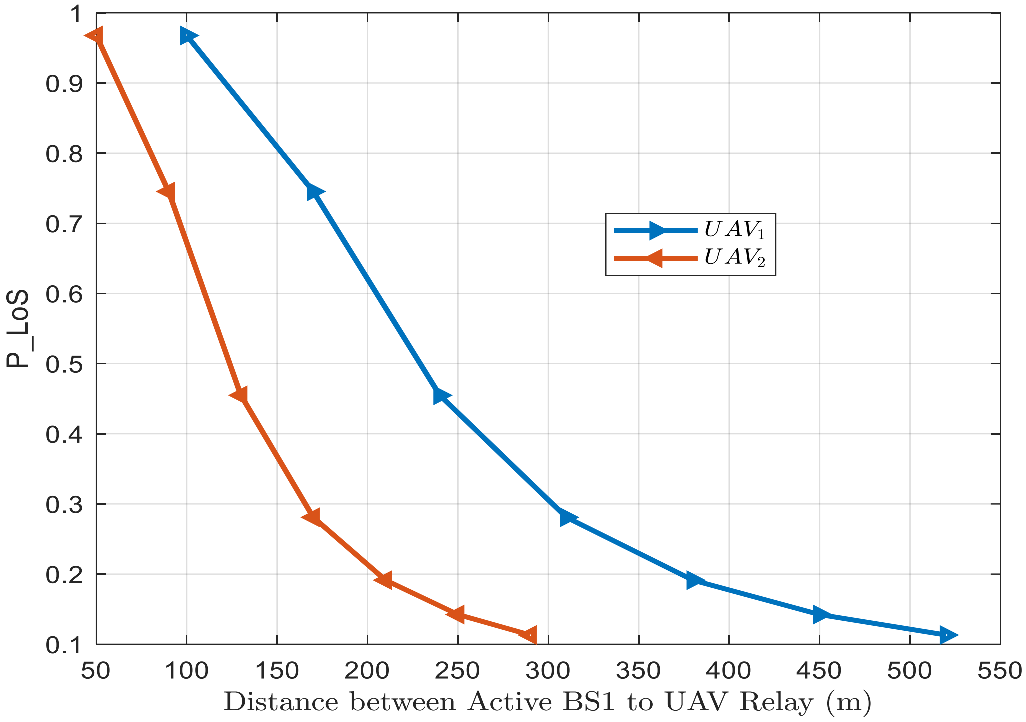


Figure 4.2. PLoS versus Distance between active BS1 to UAV relay with UAV1 and UAV2.

Figure 4.3 shows the performance of the signal-to-interference-plus-noise ratio (SINR) versus the distance between active BS_1 and the UAV relay links to UAV1 and UAV2. The figure shows two lines representing the SINR values for two different UAV relay links, UAV1 and UAV2. As the distance between active BS1 and the UAV relay links increases, the SINR values decrease for both UAV relay links. This decrease in SINR values is due to the effect of the path loss exponent, which causes a reduction in signal strength as distance increases. The figure shows that the SINR for the link with UAV1 drops from approximately 6.7 dB at 100 meters to around 5 dB at 500 meters. This indicates a decrease in the quality of the signal transmission over distance.

Similarly, the SINR for the link with UAV2 drops from approximately 6.5 dB at 100 meters to around 3.6 dB at 500 meters, a more significant decrease in SINR compared to the link with UAV1. These results suggest that the link with UAV1 may be more suitable for establishing communication with active BS_1 at longer distances than with

UAV_2. However, it is essential to note that both links experience a significant decrease in SINR as distance increases, which can affect the overall performance of the communication network during a disaster event. Overall, this graph provides insights into the impact of distance on SINR values between active BS_1 and UAV relay links, which can be used to optimize communication networks and ensure adequate disaster recovery. It highlights the importance of considering the effect of path loss on signal strength and the need to select appropriate UAV relay links based on the distance and the required quality of the signal transmission.

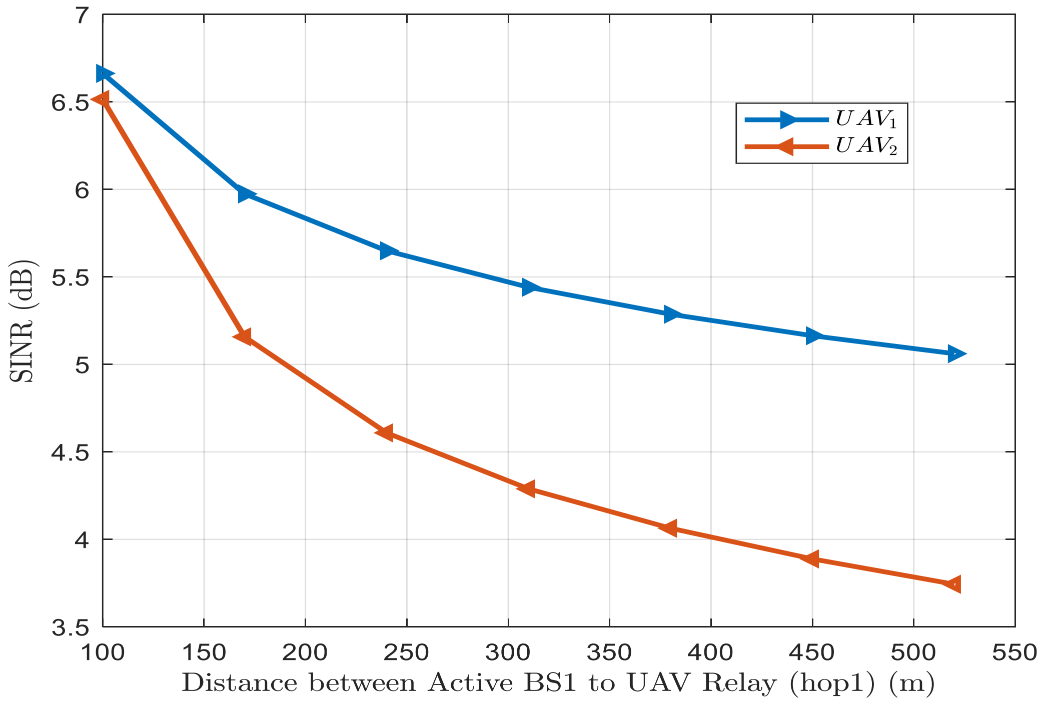


Figure 4.3. SNIR versus Distance between active BS1 to UAV relay with UAV1 and UAV2.

Figure 4.4 depicts the achievable system capacity versus the distance between the active BS_1 and UAV relay links with UAV1 and UAV2. The distance increases from 100 to 500 m, and the capacity decreases for UAV1 and UAV2. This decrease in capacity is due to increased channel interference from the base stations to the UAV nodes. For instance, for UAV1 and a bandwidth of 10 MHz, the capacity decreases from 11.2 Mbps to 6.9 Mbps; for UAV2, it drops from 11 Mbps to 2.5 Mbps. The reduction in capacity is attributed to the degradation of the signal-to-noise ratio (SNR) at the destination points due to the increased path loss exponent. This result is consistent with previous studies' findings highlighting path loss's impact on system capacity in wireless communication networks.

In summary, the results presented in Figure 4.4 emphasize the importance of optimizing the allocation of resources in disaster recovery scenarios to minimize channel interference and maximize system capacity. This makes establishing a reliable communication network that facilitates practical disaster recovery efforts possible.

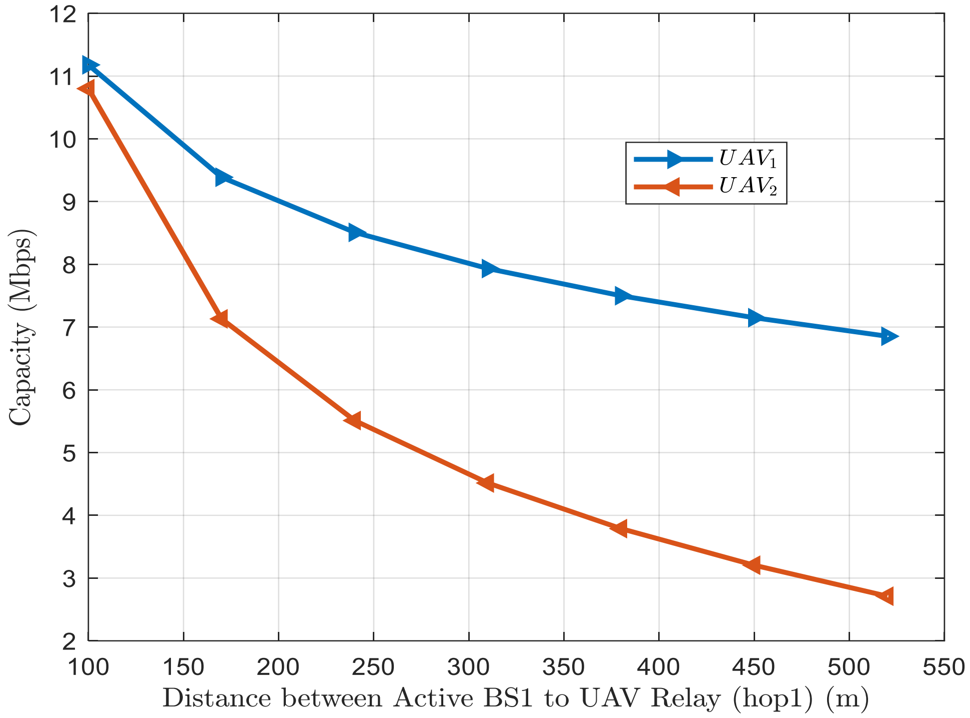


Figure 4.4. Capacity versus Distance between active BS1 to UAV relay with UAV1 and UAV2.

Figure 4.5 depicts the energy efficiency performance of the communication system in a disaster scenario Dependent on the distance between the active Base Station 1 (BS1) in the coverage zone and the relay located at the edge of the coverage area. As stated, in a disaster scenario, network resources are limited, increasing the traffic intensity and leading to a higher probability of traffic loss. Therefore, energy efficiency is crucial for communication during disasters as it helps reduce the energy consumed during the relay hops and save time. The simulation results show that the energy efficiency performance is stable at 0.3 Mbits/joule when the distance between the active BS_1 and relay is 100 m. This stability results from the predetermined bandwidth and path loss parameters. However, as the distance increases, the energy efficiency performance decreases, indicating that the system requires more energy to transmit a unit of information. This decrease in energy efficiency is observed for both UAV_1 and UAV_2.

Overall, the results of Figure 4.5 suggest that energy efficiency is an important consideration when designing communication systems for disaster scenarios. As the separation distance between the active BS1 and the relay increases, the system's energy efficiency decreases, requiring more energy to transmit information. Therefore, system designers must optimize the communication network's energy efficiency to minimize power consumption during disasters and ensure reliable communication. On the other hand, the energy efficiency performance decreased from 0.3 Mbits/joule to 0.18 Mbits/joule when the distance between the BS1-relay increased from 100 m to 500 m for the UAV1 link communication. On the other side, energy efficiency decreased from 0.3 Mbits/joule to 0.07 Mbits/joule for the link communication to UAV2 Because of the reduced spectral efficiency of the channels and the heightened path loss experienced by the nodes as they receive signals.

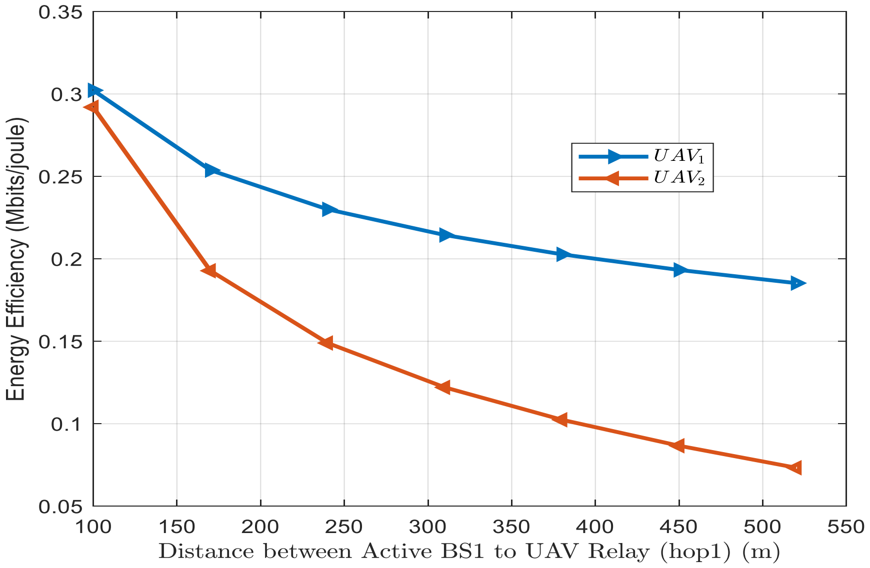


Figure 4.5. Energy efficiency Versus Distance between active BS1 to UAV relay with UAV1 and UAV2.

Figure 4.6 presents the spectral efficiency versus the distance between the active BS_1 and the UAV relay with UAV1 and UAV2 in different locations. The figure indicates a decrease in spectral efficiency for all scenarios and other UAV locations within the 100 m – 500 m distance due to increased UAV interferences from the base station. As a result, the spectral efficiency is affected by the interference caused by the base station, which limits the channel's capacity to transmit data effectively. In contrast, the figure shows increased spectral efficiency by increasing the bandwidth for all scenarios and different path loss values within the distance range of 100 m. The increase in bandwidth allows for more opportunities for the channel to access the system, reducing the interference caused by the base station, which increases spectral efficiency. In disaster scenarios, spectral efficiency is critical in ensuring effective communication between the affected areas. The decrease in spectral efficiency due to interference from the base station highlights the importance of optimizing network resources and reducing interference to enhance spectral efficiency.

Moreover, increasing spectral efficiency by increasing bandwidth provides insights into optimizing network resources during disaster events, as it offers opportunities to reduce interference and improve communication performance.

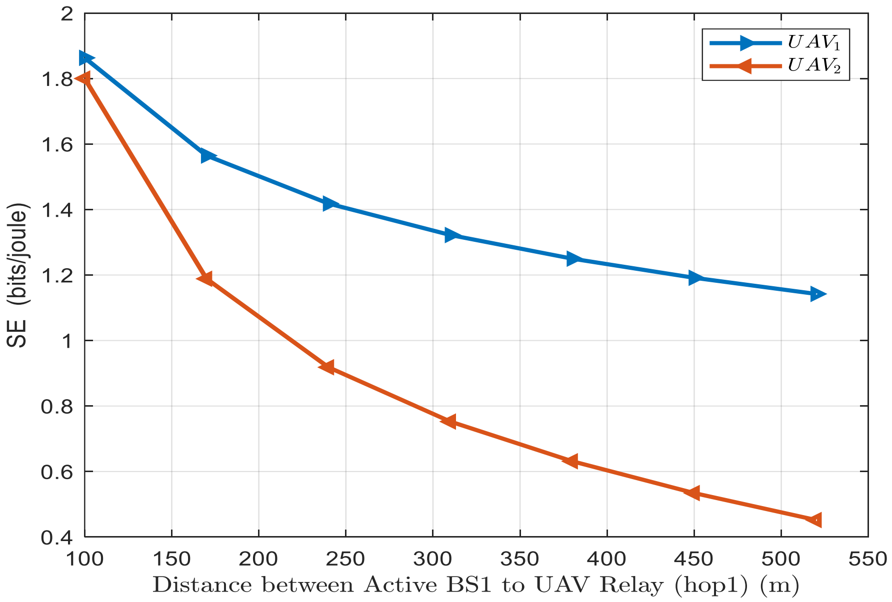


Figure 4.6. Spectrum efficiency versus Distance between active BS1 to UAV relay with UAV1 and UAV2.

Table 4.1 presents a numerical analysis of Hop1 (BS_1 to UAV Relay) on the distance versus the capacity and energy efficiency for UAV1 and UAV2. The table shows the distance between the nodes in meters, the capacity in Mbps for UAV1 and UAV2, and the energy efficiency in Mb/j for UAV1 and UAV2.

The results show that as the distance between nodes increases, the capacity for both UAV1 and UAV2 decreases. The energy efficiency for UAV1 and UAV2 decreases as the distance between nodes increases. At a distance of 100 meters, the capacity for UAV_1 is 11.1790 Mbps, and for UAV2 it is 10.7999 Mbps, while the energy efficiency for UAV1 is 0.3022 Mb/j and for UAV2 it is 0.2920 Mb/j. At a distance of 520 meters, the capacity for UAV_1 is 6.8538 Mbps, and for UAV2 it is 2.7114 Mbps, while the energy efficiency for UAV1 is 0.1853 Mb/j and for UAV2 it is 0.0733 Mb/j. Overall, the table provides valuable information on the impact of distance on the capacity and energy efficiency of the UAV communication system, which can be useful for optimizing system performance.

Table 4.1. Numerical Analysis of Hop_1 (BS_1 to UAV Relay)

Distance	**Capacity (Mbps) UAV_1**	**Capacity (Mbps) UAV_2**	**EE (Mb/j) UAV_1**	**EE (Mb/j) UAV_2**
100	11.1790	10.7999	0.3022	0.2920
170	9.3881	7.1311	0.2538	0.1928
240	8.5093	5.5102	0.2300	0.1490
310	7.9326	4.5150	0.2145	0.1221
380	7.4994	3.7881	0.2027	0.1024
450	7.1494	3.2052	0.1933	0.0867
520	6.8538	2.7114	0.1853	0.0733

4.3. ANALYSIS OF PERFORMANCE IN HOP_2

In Figure 4.7, the performance of the SINR is plotted against the distance between UAVs in hop_2 with UAV3 and UAV4. The figure indicates that as the distance between the UAVs increases from 50 to 1000 meters, there is a noticeable decrease in the SINR for all scenarios. Specifically, the SINR drops from 7.4 dB to 5.5 dB for the link between UAV3 and UV1 with a fixed bandwidth of 10 MHz, while it drops from 7.4 dB to 5.7 dB for the link between UAV4 and UV1. The decrease in SINR can be attributed to the path loss exponent, which affects the SNR at the destination points and the fixed bandwidth that increases the interference at the received destination, reducing received signals. This implies that for longer distances, the performance of the communication system may not be as effective due to lower SINR values.

Overall, the findings in Figure 4.7 suggest that the distance between UAVs significantly impacts the performance of the communication system. Optimizing the distance between the UAVs is crucial to ensure a reliable and efficient communication network.

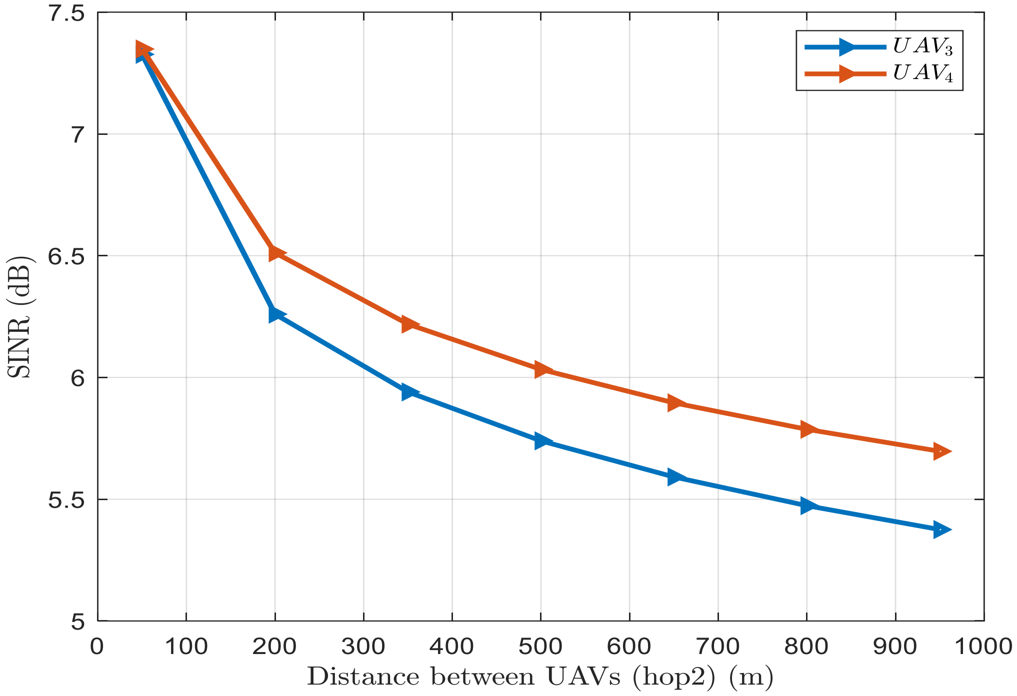


Figure 4.7. Analysis of SINR versus Distance between UAVs in hop2 with UAV3 And UAV 4.

Figure 4.8 illustrates the system capacity performance versus the distance between UAVs in hop_2 with different locations of UAV3 and UAV4. The capacity decreases as the distance between UAVs increases, with a reduction from 13 Mbps to 8.75 Mbps for the link communication on UAV4. In contrast, for the link communication to UAV3, the capacity decreased from 13 Mbps to 7.8 Mbps. This reduction in capacity is attributed to the path loss exponent's high impact and the system's low-located bandwidth. The path loss exponent negatively affects the destination node's signal-to-noise ratio (SNR).

In contrast, the bandwidth affects the system's capacity by limiting the amount of data transmitted at a given time. As the distance between UAVs increases, the path loss exponent increases, resulting in decreased SNR at the destination nodes, negatively affecting the system capacity. However, for the link communication to UAV3, the reduction in capacity is also attributed to the increased effect of the path loss between the source and destination nodes, coupled with more located bandwidth for signals. This implies that as the path loss exponent increases, there is a need for a broader bandwidth to counter the adverse effects on the system's capacity. Overall, Figure 4.8 demonstrates the impact of path loss and bandwidth on the system capacity performance, emphasizing the need for optimized system design in UAV networks.

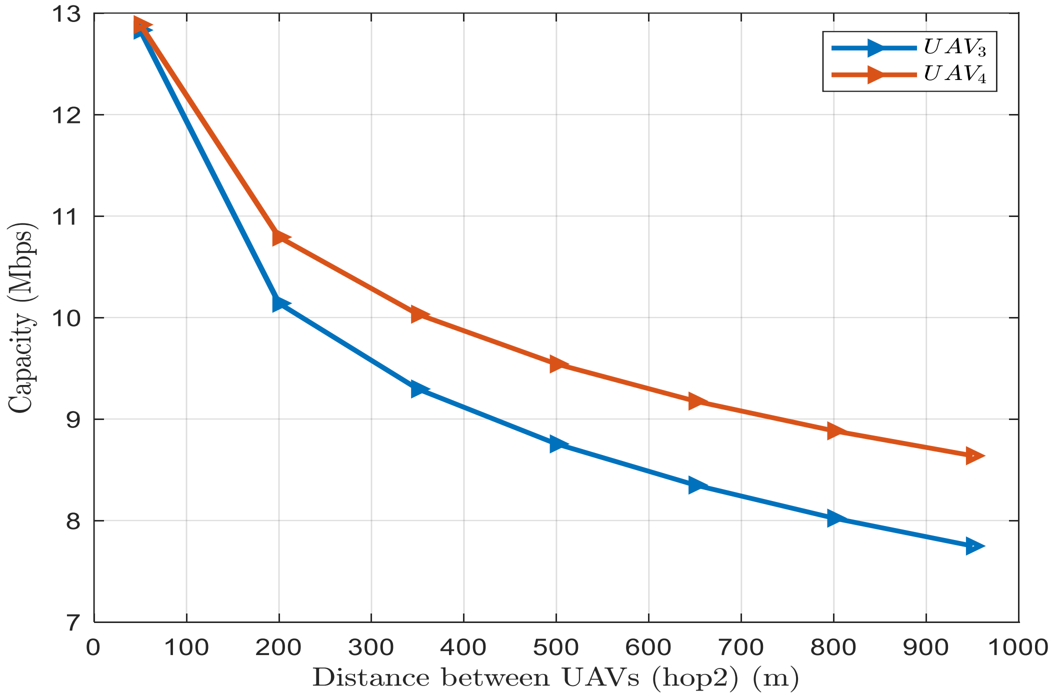


Figure 4.8. Analysis of capacity versus Distance between UAVs in hop_2.

Figure 4.9 depicts the energy efficiency performance of communication during disasters, which is crucial in saving power consumption and enabling longer communications in resource-constrained scenarios. The diagram displays the relationship between energy efficiency and the separation distance of the UAVs in hop_2 where the communication link is established between UAV_3 and UAV_4. The results demonstrate that the energy efficiency performance is stable at 0.35 Mbits/joule when the distance between the UAVs is 50 m, owing to the system's fixed bandwidth and path loss characteristics. However, as the distance between the UAVs increases from 50 m to 950 m, the energy efficiency performance decreases for each scenario with different locations of UAV_3 and UAV_4. Specifically, the energy efficiency performance decreases from 0.35 Mbits/joule to 0.24 Mbits/joule for the UAV_4 link communication and from 0.35 Mbits/joule to 0.22 Mbits/joule for the UAV_3 link communication. The reduction in energy efficiency is caused by the decreased spectral efficiency of the channels and the increased path loss experienced by the nodes, which in turn results in a weaker signal-to-noise ratio (SNR) at the destination nodes.

Figure 4.9 highlights the importance of optimizing the distance between UAVs in hop_2 to achieve higher energy efficiency and reduce power consumption during communication in disaster scenarios. By carefully selecting the optimal distance, the system can maintain a high energy efficiency performance and conserve power, thus enabling extended communication and ensuring reliable connectivity in resource-constrained environments.

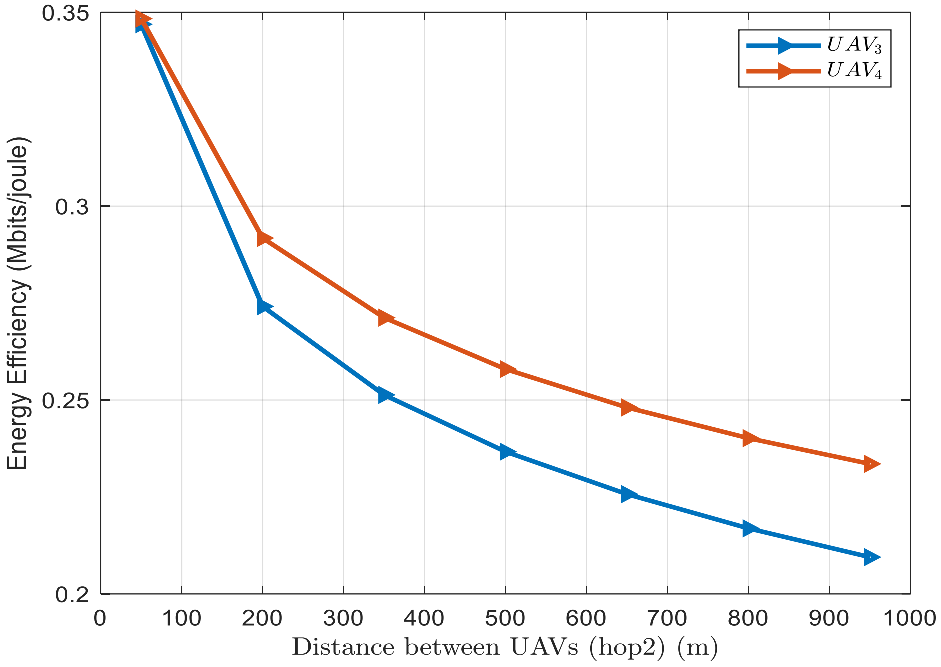


Figure 4.9. Analysis of energy efficiency versus Distance between UAVs in hop 2 with UAV3 And UAV 4.

Figure 4.10 depicts the spectral efficiency performance versus the distance between UAVs in hop2 with different locations of UAV3 and UAV4. As the distance between the UAVs increases from 50m to 950m, the spectral efficiency decreases from 2.15Mbits/Hz/s to 1.45Mbits/Hz/s for the UAV_4 link communication and from 2.15Mbits/Hz/s to 1.3Mbits/Hz/s for the UAV_3 link communication. The decrease in spectral efficiency can be attributed to the path loss exponent, which affects the SNR at the receiver nodes.

Moreover, increasing the bandwidth provides more opportunity channels for the user devices to communicate between the functional and dysfunctional areas efficiently, which can improve spectral efficiency.

Additionally, the figure shows that increasing the bandwidth can improve the spectral efficiency performance. The bandwidth increase can reduce interference and improve spectral efficiency by assigning more opportunity channels for user devices to communicate between functional and dysfunctional areas. Thus, bandwidth allocation is an essential factor in improving spectral efficiency. Therefore, the results obtained from Figure 4.10 suggest that improving the system's bandwidth can enhance spectral efficiency performance in the communication between UAVs in hop_2. However, the impact of the path loss exponent cannot be neglected, and it should be considered when designing communication systems for UAVs in disaster scenarios.

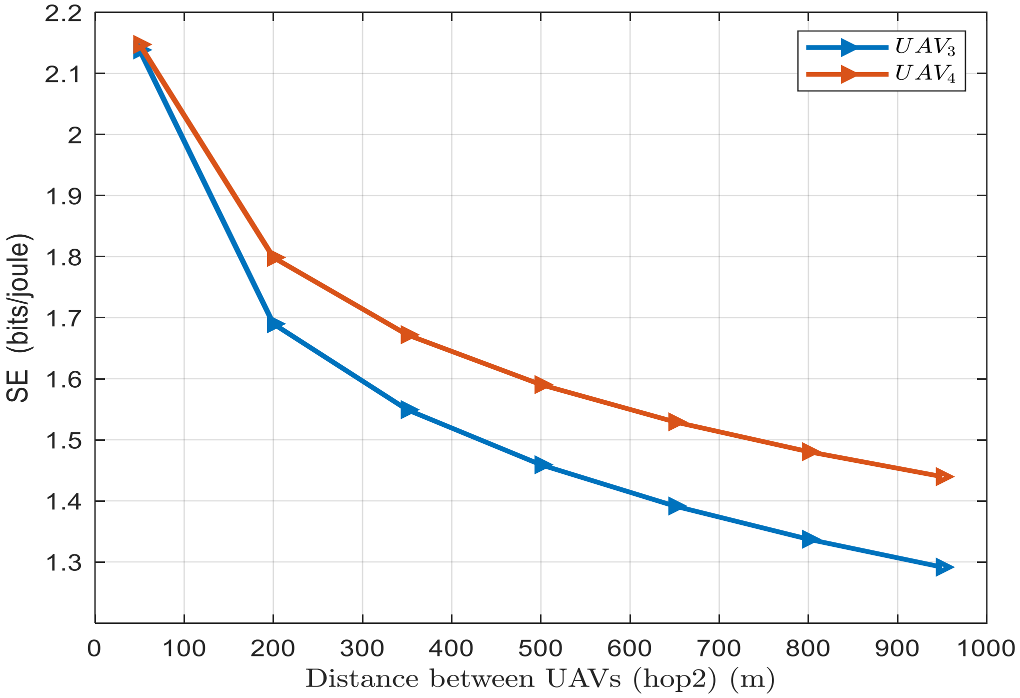


Figure 4.10. Analysis of spectrum efficiency versus Distance between UAVs in hop2 with UAV3 And UAV 4.

Table 4.2 presents the results of a numerical analysis of Hop_2 between two UAVs, UAV_3, and UAV4, regarding distance, capacity (Mbps), and energy efficiency (Mb/j). As the distance between UAVs increases, the capacity decreases while the energy efficiency slightly improves. At a distance of 50 meters, the capacity is at its highest, with UAV_3 and UAV_4 having a capacity of over 12 Mbps. As the distance increases to 950 meters, the capacity drops to 7.7488 Mbps for UAV3 and 8.6384 Mbps for UAV4. The energy efficiency for both UAV3 and UAV4 ranges from 0.2095 Mb/j to 0.3469 Mb/j. The results suggest that Hop_2 communication between UAVs can achieve high capacity and reasonable energy efficiency over short distances.

Table 4.2. Numerical Analysis of Hop_2 (Between UAV)

Distance	Capacity (Mbps) UAV_3	Capacity (Mbps) UAV_4	EE (Mb/j) UAV_3	EE (Mb/j) UAV_4
50	12.8320	12.8857	0.3469	0.3484
200	10.1405	10.7925	0.2741	0.2918
350	9.2963	10.0330	0.2513	0.2712
500	8.7549	9.5425	0.2367	0.2580
650	8.3495	9.1767	0.2257	0.2481
800	8.0232	8.8836	0.2169	0.2402
950	7.7488	8.6384	0.2095	0.2335

4.4. ANALYSIS PERFORMANCE IN HOP_3

Figure 4.11 presents the analysis of Received signal strength (RSS) for hop_3 of UAV_3 and UAV_4 communication to UAV_5, which is crucial to ensure effective communication during disasters and minimize power consumption. The figure illustrates a decrease in the Rss performance as the distance between the UAV's communication increases from 50-400m. Specifically, in the link communication with UAV4, the Rss and version decreased from -58 dB to -76 dB. Similarly, in the link communication with UAV_3, the Rss, and performance decreased from -62dB to -76 dB. The decrease in Rss and performance can be attributed to the increased path loss, which hurts the Signal-to-Noise Ratio (SNR) performance at the distance nodes. The SNR performance is critical in determining the quality of the received signal and the overall communication performance. As the distance between the nodes increases, the signal strength decreases, expanding the path loss and decreasing the SNR. This leads to decreased Rss performance and affects the overall communication performance. In conclusion, Figure 4.11 highlights the importance of minimizing path loss and maintaining a strong SNR performance to ensure effective communication during disasters and reduce power consumption.

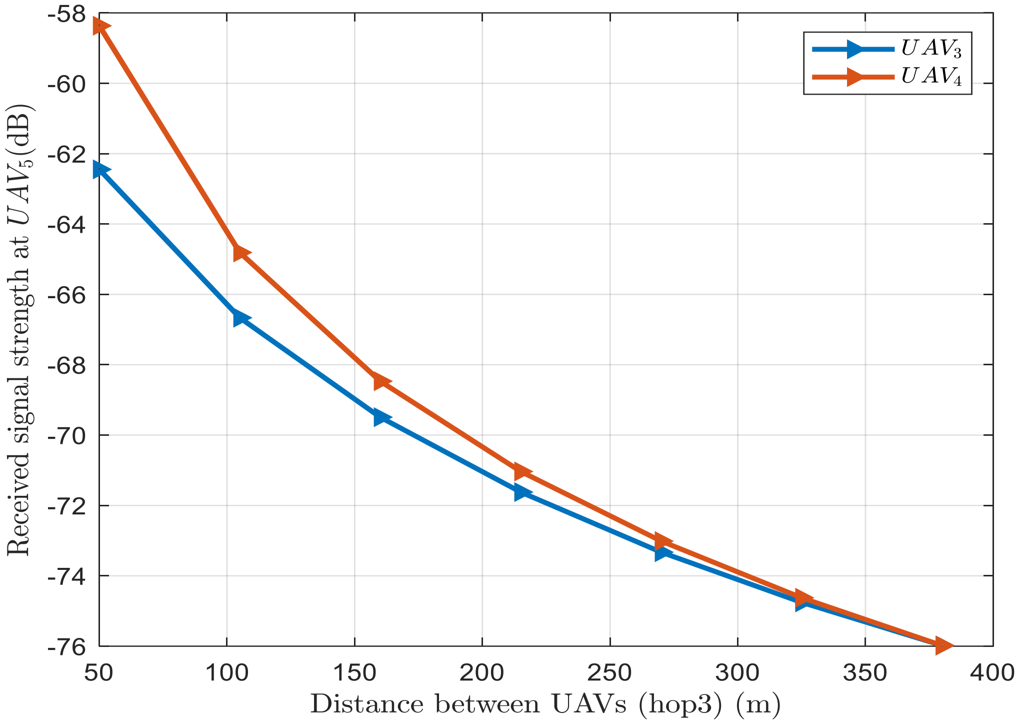


Figure 4.11. Analysis of Rss versus Distance between UAVs in hop3 with UAV3 and UAV 4.

CHAPTER 5

SUMMARY AND FUTURE WORK

5.1. SUMMARY

This project studies the recovery of disaster communication when the infrastructure network is damaged due to natural disaster events. The Multi UAV relay hop is essential in transferring the wireless signal from functional to dysfunctional areas. The U2U communication has highlighted several ideas to establish the communication between the source and destination with edge communication with a cellular system and ad-hoc network. A scenario of multi-hop UAV communications where the pair communicates with each other through another U2U is investigated. The result measures and analyzes the performance of transferring the wireless signals from the function to the dysfunctional area. The performance of the wireless signals transferring between in-coverage and out-of-coverage areas is evaluated by the system capacity, spectral efficiency, and energy efficiency, which are affected by the locations of UAVs and the bandwidth of the channels. In addition, the distance near and far from the UAVs relay hope affects the performance of the transmutation wireless signal to the node located in the out-of-coverage area. Additionally, when the two UAVs are close, UAV hop communication still gives a higher energy efficiency with efficient capacity, spectral efficiency, and energy efficiency.

5.2. FUTURE WORK

The studies conducted in disaster recovery and public safety scenarios have identified several limitations that must be addressed for more effective solutions. One major challenge is the limited battery life of relay nodes, which affects the transmission of wireless signals over longer distances. Additionally, ensuring an effective outage probability of relays at the edge and outside the coverage area remains a concern.

Various solutions have been proposed to overcome these limitations, such as using clustering UAVs in the air channel to provide wireless coverage to ground nodes. However, the power consumption of both the source and destination nodes still presents a challenge, as it significantly impacts the recovery time and the ability to cover extended distances. It is recommended to incorporate energy harvesting techniques, clustering, and multi-hop UAV communications for user devices in wireless coverage sources to address this. The power constraints can be alleviated by harnessing energy from the environment, improving efficiency and extended coverage. Furthermore, the energy efficiency of UAV connectivity can be enhanced by leveraging dynamic deep-learning development models specifically designed for disaster recovery. These models can adapt to changing conditions and optimize the utilization of resources, leading to more effective and sustainable communication systems in disaster-stricken areas. Another aspect to consider for future work is the integration of smart devices compatible with the Internet of Fly Things (IOFT) and the Internet of Public Safety Things (IOPST). Leveraging IOFT and IOPST's capabilities can further enhance disaster communications' resilience and efficiency by enabling seamless connectivity, real-time data sharing, and intelligent decision-making. The suggested algorithm for best partner selection based on high SNR can be extended for long distance and warranty QoS.

Lastly, exploring the potential of incorporating Beyond 5G (B5G) technologies in disaster recovery communications is essential. B5G, with its advanced features and capabilities, holds the promise of significantly improving the efficiency and reliability of disaster communications systems.

In summary, future work should address the limitations of battery lifetime, long-distance wireless transmission, and effective outage probability in disaster recovery and public safety scenarios. This can be achieved by employing energy harvesting techniques, leveraging dynamic deep-learning development models, integrating smart devices compatible with IOFT and IOPST, and exploring the benefits of B5G technologies. More efficient and resilient disaster communication solutions can be developed by advancing these research areas.

REFERENCES

[1] M. Casoni, C. A. Grazia, M. Klapez, N. Patriciello, A. Amditis, and E. Sdongos, "Integration of satellite and LTE for disaster recovery," *IEEE Communications Magazine*, vol. 53, no. 3, pp. 47-53, 2015.

[2] A. Jarwan, A. Sabbah, and M. Ibnkahla, "Data transmission reduction schemes in WSNs for efficient IoT systems," *IEEE J. Sel. Areas Commun.,* vol. 37, no. 6, pp. 1307-1324, 2019.

[3] K. Byeong Cheol and H. S. Kong, "Efficient Operation Plan of 119 Comprehensive Situation Room According to the Nature of Disaster Response in Korea," *Turkish Journal of Computer and Mathematics Education (TURCOMAT),* vol. 12, no. 13, pp. 6006-6013, 2021.

[4] K. Ali, H. X. Nguyen, Q.-T. Vien, P. Shah, and Z. Chu, "Disaster management using D2D communication with power transfer and clustering techniques," *IEEE Access,* vol. 6, pp. 14643-14654, 2018.

[5] C. Yu, L. Yu, Y. Wu, Y. He, and Q. Lu, "Uplink scheduling and link adaptation for narrowband Internet of Things systems," *IEEE Access,* vol. 5, pp. 1724-1734, 2017.

[6] P. Kumar, N. Chauhan, M. Kumar, and L. K. Awasthi, "Clustering based opportunistic traffic offloading technique for device-to-device communication," *Int J Syst Assur Eng,* pp. 1-13, 2021.

[7] R. Kanthavel, S. Indra Priyadharshini, D. Sudha, K. Sundara Velrani, and R. Dhaya, "Multi-hoped cooperative communication-based wireless underground sensor network design," *International Journal of Communication Systems,* vol. 35, no. 10, p. e5174, 2022.

[8] Y. Zhang and J. Li, "Study on Spectrum Allocation and Optimization of Wireless Communication Networks Based on SFOA," *Wireless Communications and Mobile Computing,* vol. 2021, 2021.

[9] I. Ioannou, C. Christophorou, V. Vassiliou, and A. Pitsillides, "Performance Evaluation of Transmission Mode Selection in D2D communication," in *2021 11th IFIP International Conference on New Technologies, Mobility and Security (NTMS),* 2021: IEEE, pp. 1-7.

[10] I. P. Chochliouros *et al.*, "5G for the Support of Public Safety Services," *Wirel. Pers. Commun.,* pp. 1-28, 2021.

[11] A. Baliga, I. Subhod, P. Kamat, and S. Chatterjee, "Performance evaluation of the quorum blockchain platform," *arXiv preprint arXiv:1809.03421,* 2018.

[12] S. V. A. Amanuel and S. Y. A. Ameen, "Device-to-device communication for 5G security: A review," *Journal of Information Technology and Informatics,* vol. 1, no. 1, pp. 26-31, 2021.

[13] L. Wang, T. Han, Q. Li, J. Yan, X. Liu, and D. Deng, "Cell-less communications in 5G vehicular networks based on vehicle-installed access points," *IEEE wireless communications,* vol. 24, no. 6, pp. 64-71, 2017.

[14] A. Saif *et al.*, "Distributed Clustering for User Devices Under Unmanned Aerial Vehicle Coverage Area during Disaster Recovery," *arXiv preprint arXiv:2103.07931*, 2021.

[15] Q.-N. Tran *et al.*, "D2D Multi-hop Multi-path Communications in B5G Networks: A Survey on Models, Techniques, and Applications," *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems,* vol. 7, no. 25, p. 167839, 2021.

[16] Y. A. Sambo, M. Z. Shakir, K. A. Qaraqe, E. Serpedin, and M. A. Imran, "Expanding cellular coverage via cell-edge deployment in heterogeneous networks: Spectral efficiency and backhaul power consumption perspectives," *IEEE Communications Magazine,* vol. 52, no. 6, pp. 140-149, 2014.

[17] C. G. Kennedy, K. Okokpujie, E. Noma-Osaghae, K. S. Bhandari, and J. M. Kalibbala, "On Information Technology Disaster Recovery and Its Relevance to Business Continuity," in *International conference on smart computing and cyber security: strategic foresight, security challenges and innovation*, 2022: Springer, pp. 90-99.

[18] L. Babun, "Extended coverage for public safety and critical communications using multi-hop and D2D communications," 2015.

[19] W. Yu, H. Xu, J. Nguyen, E. Blasch, A. Hematian, and W. Gao, "Survey of public safety communications: User-side and network-side solutions and future directions," *IEEE Access,* vol. 6, pp. 70397-70425, 2018.

[20] S. Adibi, "A mobile health network disaster management system," in *2015 seventh international conference on ubiquitous and future networks*, 2015: IEEE, pp. 424-428.

[21] J. Lyu, Y. Zeng, and R. Zhang, "UAV-aided offloading for cellular hotspot," *IEEE Trans. Wirel. Commun.,* vol. 17, no. 6, pp. 3988-4001, 2018.

[22] R. Ramanathan and J. Redi, "A brief overview of ad hoc networks: challenges and directions," *IEEE communications Magazine,* vol. 40, no. 5, pp. 20-22, 2002.

[23] D. Mirzoev, "Low rate wireless personal area networks (lr-wpan 802.15. 4 standard)," *arXiv preprint arXiv:1404.2345,* 2014.

[24] Y. Kishi, K. Tabata, T. Kitahara, Y. Noishiki, A. Idoue, and S. Nomoto, "Wireless node architecture and its implementation for multi-hop mesh networks

in IP-based broadband fixed wireless access systems," *IEICE Trans. Commun.,* vol. 88, no. 3, pp. 1202-1210, 2005.

[25] D. Takaishi, Y. Kawamoto, H. Nishiyama, N. Kato, F. Ono, and R. Miura, "Virtual cell based resource allocation for efficient frequency utilization in unmanned aircraft systems," *IEEE Transactions on Vehicular Technology,* vol. 67, no. 4, pp. 3495-3504, 2017.

[26] M. Mezzavilla *et al.*, "Public safety communications above 6 GHz: Challenges and opportunities," *IEEE Access,* vol. 6, pp. 316-329, 2017.

[27] J. Pokorny *et al.*, "Concept design and performance evaluation of UAV-based backhaul link with antenna steering," *Journal of Communications and Networks,* vol. 20, no. 5, pp. 473-483, 2018.

[28] K. G. Panda, S. Das, D. Sen, and W. Arif, "Design and deployment of UAV-aided post-disaster emergency network," *IEEE Access,* vol. 7, pp. 102985-102999, 2019.

[29] E. Christy, R. P. Astuti, B. Syihabuddin, B. Narottama, O. Rhesa, and F. Rachmawati, "Optimum UAV flying path for device-to-device communications in disaster area," in *2017 International Conference on Signals and Systems (ICSigSys),* 2017: IEEE, pp. 318-322.

[30] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, "A tutorial on UAVs for wireless networks: Applications, challenges, and open problems," *IEEE communications surveys & tutorials,* vol. 21, no. 3, pp. 2334-2360, 2019.

[31] T. Darwish, G. K. Kurt, H. Yanikomeroglu, G. Senarath, and P. Zhu, "A vision of self-evolving network management for future intelligent vertical HetNet," *IEEE Wireless Communications,* vol. 28, no. 4, pp. 96-105, 2021.

[32] S. H. Alsamhi, F. Almalki, O. Ma, M. S. Ansari, and B. Lee, "Predictive estimation of optimal signal strength from drones over IoT frameworks in smart cities," *IEEE Transactions on Mobile Computing,* 2021.

[33] B. E. Y. Belmekki and M.-S. Alouini, "Unleashing the potential of networked tethered flying platforms: Prospects, challenges, and applications," *IEEE Open Journal of Vehicular Technology,* vol. 3, pp. 278-320, 2022.

[34] Y. Zeng, J. Lyu, and R. Zhang, "Cellular-connected UAV: Potential, challenges, and promising technologies," *IEEE Wireless Communications,* vol. 26, no. 1, pp. 120-127, 2018.

[35] Y. Chen, W. Feng, and G. Zheng, "Optimum placement of UAV as relays," *IEEE Commun. Lett.,* vol. 22, no. 2, pp. 248-251, 2017.

[36] A. Sharma *et al.*, "Communication and networking technologies for UAVs: A survey," *Journal of Network and Computer Applications,* vol. 168, p. 102739, 2020.

[37] F. Syed, S. K. Gupta, S. Hamood Alsamhi, M. Rashid, and X. Liu, "A survey on recent optimal techniques for securing unmanned aerial vehicles applications," *Trans. Emerg. Telecommun. Technol.,* vol. 32, no. 7, p. e4133, 2021.

[38] S. A. H. Mohsan, M. A. Khan, F. Noor, I. Ullah, and M. H. Alsharif, "Towards the unmanned aerial vehicles (UAVs): A comprehensive review," *Drones,* vol. 6, no. 6, p. 147, 2022.

[39] Q. Wu *et al.*, "A comprehensive overview on 5G-and-beyond networks with UAVs: From communications to sensing and intelligence," *IEEE J. Sel. Areas Commun.,* 2021.

[40] M. K. Shehzad, M. W. Akhtar, and S. A. Hassan, "Performance of mmWave UAV-Assisted 5G Hybrid Heterogeneous Networks," *Autonomous Airborne Wireless Networks,* pp. 97-118, 2021.

[41] Y. Mekdad *et al.*, "A survey on security and privacy issues of UAVs," *Comput. Netw.,* vol. 224, p. 109626, 2023.

[42] D. He, H. Liu, S. Chan, and M. Guizani, "How to govern the non-cooperative amateur drones?," *IEEE Network*, vol. 33, no. 3, pp. 184-189, 2019.

[43] M. A. Khan, A. Safi, I. M. Qureshi, and I. U. Khan, "Flying ad-hoc networks (FANETs): A review of communication architectures, and routing protocols," in *2017 First international conference on latest trends in electrical engineering and computing technologies (INTELLECT)*, 2017: IEEE, pp. 1-9.

[44] A. S. SHAH and M. A. KARABULUT, "Optimization of drones communication by using meta-heuristic optimization algorithms," *Sigma Journal of Engineering and Natural Sciences,* vol. 40, no. 1, pp. 108-117, 2022.

[45] J. N. Laneman and G. W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks," *IEEE Transactions on Information theory,* vol. 49, no. 10, pp. 2415-2425, 2003.

[46] T. Hiraguri *et al.*, "A cooperative transmission scheme in drone-based networks," *IEEE Transactions on Vehicular Technology,* vol. 69, no. 3, pp. 2905-2914, 2020.

[47] M. Kassab, M. Berbineau, A. Vinel, M. Jonsson, F. Garcia, and J. Soler, *Communication Technologies for Vehicles: 8th International Workshop, Nets4Cars/Nets4Trains/Nets4Aircraft 2015, Sousse, Tunisia, May 6-8, 2015. Proceedings*. Springer, 2015.

[48] Q. Wang, Z. Chen, W. Mei, and J. Fang, "Improving physical layer security using UAV-enabled mobile relaying," *IEEE Wirel. Commun. Lett.,* vol. 6, no. 3, pp. 310-313, 2017.

[49] I. Y. Abualhaol and M. M. Matalgah, "Performance analysis of multi-carrier relay-based UAV network over fading channels," in *2010 IEEE Globecom Workshops,* 2010: IEEE, pp. 1811-1815.

[50] Y. Chen, N. Zhao, Z. Ding, and M.-S. Alouini, "Multiple UAVs as relays: Multi-hop single link versus multiple dual-hop links," *IEEE Trans. Wirel. Commun.,* vol. 17, no. 9, pp. 6348-6359, 2018.

[51] T. Andre *et al.*, "Application-driven design of aerial communication networks," *IEEE Communications Magazine,* vol. 52, no. 5, pp. 129-137, 2014.

[52] A. Sargolzaei, A. Abbaspour, and C. D. Crane, "Control of cooperative unmanned aerial vehicles: review of applications, challenges, and algorithms," *Optimization, Learning, and Control for Interdependent Complex Networks,* pp. 229-255, 2020.

[53] E. Vinogradov, H. Sallouha, S. De Bast, M. M. Azari, and S. Pollin, "Tutorial on UAV: A blue sky view on wireless communication," *arXiv preprint arXiv:1901.02306,* 2019.

[54] S. Goudarzi, S. A. Soleymani, W. Wang, and P. Xiao, "UAV-Enabled Mobile Edge Computing for Resource Allocation Using Cooperative Evolutionary Computation," *IEEE Transactions on Aerospace and Electronic Systems,* 2023.

[55] X. Fan, J. Hu, and K. Yang, "UAV-aided data and energy integrated network: System design and prototype development," *China Commun.,* 2023.

[56] T. R. Beegum, M. Y. I. Idris, M. N. B. Ayub, and H. A. Shehadeh, "Optimized routing of UAVs using Bio-Inspired Algorithm in FANET: A Systematic Review," *IEEE Access,* 2023.

[57] S. A. H. Mohsan, N. Q. H. Othman, Y. Li, M. H. Alsharif, and M. A. Khan, "Unmanned aerial vehicles (UAVs): practical aspects, applications, open challenges, security issues, and future trends," *Intelligent Service Robotics,* pp. 1-29, 2023.

[58] W. Chen *et al.*, "5G-Advanced Towards 6G: Past, Present, and Future," *arXiv preprint arXiv:2303.07456,* 2023.

[59] B. Ji, Y. Li, B. Zhou, C. Li, K. Song, and H. Wen, "Performance analysis of UAV relay assisted IoT communication network enhanced with energy harvesting," *IEEE Access,* vol. 7, pp. 38738-38747, 2019.

[60] J. Lansky *et al.*, "Reinforcement Learning-Based Routing Protocols in Flying Ad Hoc Networks (FANET): A Review," *Mathematics,* vol. 10, no. 16, p. 3017, 2022.

[61] X. Wei, Z. Yi, W. Li, L. Zhao, and W. Zhang, "Energy harvesting fueling the revival of self-powered unmanned aerial vehicles," *Energy Conversion and Management,* vol. 283, p. 116863, 2023.

[62] M. J. Abdel-Rahman, A. M. AlWaqfi, J. K. Atoum, M. A. Yaseen, and A. B. MacKenzie, "A Novel Multi-Objective Sequential Resource Allocation Optimization for UAV-Assisted VLC," *IEEE Transactions on Vehicular Technology,* 2023.

[63] S. Aljubayrin, "Computational energy efficient trajectory planning for UAV-enabled 6G MEC communication network," *Physical Communication,* p. 102000, 2023.

[64] J. Lee and V. Friderikos, "Multiple UAVs Trajectory Optimization in Multi-Cell Networks with Adjustable Overlapping Coverage," *IEEE Internet of Things Journal,* 2023.

[65] S. Javaid *et al.*, "Communication and Control in Collaborative UAVs: Recent Advances and Future Trends," *IEEE Transactions on Intelligent Transportation Systems,* 2023.

[66] N. Rahmatov and H. Baek, "RIS-carried UAV communication: Current research, challenges, and future trends," *ICT Express,* 2023.

[67] F. Liu, S. Yuan, W. Meng, R. Su, and L. Xie, "Multiple Non-Cooperative Targets Encirclement by Relative Distance Based Positioning and Neural Anti-Synchronization Control," *IEEE Transactions on Industrial Electronics,* 2023.

[68] S. Sharmin, I. Ahmedy, and R. Md Noor, "An Energy-Efficient Data Aggregation Clustering Algorithm for Wireless Sensor Networks Using Hybrid PSO," *Energies,* vol. 16, no. 5, p. 2487, 2023.

[69] X. Chen, Z. Feng, Z. Wei, F. Gao, and X. Yuan, "Performance of joint sensing-communication cooperative sensing UAV network," *IEEE Transactions on Vehicular Technology,* vol. 69, no. 12, pp. 15545-15556, 2020.

[70] L. Sboui, H. Ghazzai, Z. Rezki, and M.-S. Alouini, "Achievable rates of UAV-relayed cooperative cognitive radio MIMO systems," *IEEE Access,* vol. 5, pp. 5190-5204, 2017.

[71] V. Rodríguez-Fernández, H. D. Menéndez, and D. Camacho, "Automatic profile generation for uav operators using a simulation-based training environment," *Progress in Artificial Intelligence,* vol. 5, no. 1, pp. 37-46, 2016.

[72] S. Arzykulov, A. Celik, G. Nauryzbayev, and A. M. Eltawil, "UAV-assisted cooperative & cognitive NOMA: deployment, clustering, and resource allocation," *IEEE Transactions on Cognitive Communications and Networking,* vol. 8, no. 1, pp. 263-281, 2021.

[73] I. Mahmud and Y.-Z. Cho, "Adaptive hello interval in FANET routing protocols for green UAVs," *IEEE Access,* vol. 7, pp. 63004-63015, 2019.

[74] M. Matracia, N. Saeed, M. A. Kishk, and M.-S. Alouini, "Post-Disaster Communications: Enabling Technologies, Architectures, and Open Challenges," *arXiv preprint arXiv:2203.13621,* 2022.

[75] S. H. Alsamhi *et al.*, "UAV computing-assisted search and rescue mission framework for disaster and harsh environment mitigation," *Drones,* vol. 6, no. 7, p. 154, 2022.

[76] O. Bushnaq, M. A. Kishk, A. Celik, M.-S. Alouini, and T. Y. Al-Naffouri, "Cellular traffic offloading through tethered-UAV deployment and user association," 2020.

[77] G. Deepak, A. Ladas, Y. A. Sambo, H. Pervaiz, C. Politis, and M. A. Imran, "An overview of post-disaster emergency communication systems in the future networks," *IEEE Wireless Communications,* vol. 26, no. 6, pp. 132-139, 2019.

[78] A. Khan, S. Gupta, and S. K. Gupta, "Cooperative Control between Multi-UAVs for Maximum Coverage in Disaster Management: Review and Proposed Model," in *2022 2nd International Conference on Computing and Information Technology (ICCIT)*, 2022: IEEE, pp. 271-277.

[79] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and E. Ever, "D2D multi-hop relaying services towards disaster communication system," in *2017 24th international conference on telecommunications (ICT)*, 2017: IEEE, pp. 1-5.

[80] A. Saif, K. Dimyati, K. A. Noordin, N. S. M. Shah, Q. Abdullah, and F. Mukhlif, "Unmanned aerial vehicles for post-disaster communication networks," in *2020 IEEE 10th International Conference on System Engineering and Technology (ICSET)*, 2020: IEEE, pp. 273-277.

[81] Q. Feng, J. McGeehan, E. K. Tameh, and A. R. Nix, "Path loss models for air-to-ground radio channels in urban environments," in *2006 IEEE 63rd vehicular technology conference*, 2006, vol. 6: IEEE, pp. 2901-2905.

[82] A. Al-Hourani, S. Kandeepan, and A. Jamalipour, "Modeling air-to-ground path loss for low altitude platforms in urban environments," in *2014 IEEE global communications conference*, 2014: IEEE, pp. 2898-2904.

[83] J. A. Hassan and S. A. Mustafa, "An efficient partner selection method to overcome the interference effect in wireless networks," *IEEE Access,* vol. 7, pp. 33677-33685, 2019.

[84] J. Z. Moghaddam, M. Usman, and F. Granelli, "A device-to-device communication-based disaster response network," *IEEE Transactions on Cognitive Communications and Networking,* vol. 4, no. 2, pp. 288-298, 2018.

[85] Y. Feng and Z. Pan, "Optimization of remote public medical emergency management system with low delay based on internet of things," *Journal of Healthcare Engineering,* vol. 2021, 2021.

RESUME

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