الجمهورية الجزائرية الديمقراطية الشعبية
PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA
وزارة التعليم العالي والبحث العلمي
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC
جامعة عمار ثليجي بالأغواط
UNIVERSITY OF Ammar Telidji LAGHOUAT

كلية العلوم
FACULTY OF SCIENCES
قسم الاعلام الالي
DEPARTMENT OF COMPUTER SCIENCE

Master’s Thesis

Field: Mathematics and Computer Science
Specialty: Computer Science
Option: Distributed Networks, Systems, and Applications

By:

BENHAMZA BOUTHEINA

BENCHETTOUH DOUAA NOUR ELHOUDA

TOPIC

Crowd-Sourced and Incentive-Driven UAV System to Assist with Network Slices

Defended publicly on June 28th, 2025, before a jury composed of:

Pr. Chaib Noureddine	Prof	President
Dr. Bensaad Mohamed Lahcen	M.C.B	Examiner
Dr. Babaghayou Messaoud	M.A.B	Examiner
Dr. Bouzid Tarek	M.A.B	Supervisor

Academic Year 2024/2025

Dedication

I dedicate this humble work to my dear parents, who have been my constant support and motivation throughout my academic journey.
Thank you both for your unwavering support and continuous encouragement, which made the completion of this work a reality.

To my beloved brothers and sisters, who stood by me throughout my journey in preparing this thesis.
Thank you all for your unconditional support.

To my esteemed family and everyone who surrounded me with love A and support during my academic journey, thank you from the bottom of my heart.

Finally, to all my loyal friends, who supported me through various stages of completing this work.
Thank you for your kind presence in my life.

Boutheina

Dedication

{نَرْفَعُ دَرَجَاتٍ مَّن نَّشَاءُ ۗ وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ (76) } سورة يوسف

I am sincerely thankful
To myself, for the hours of hard work and determination, for every challenge faced and overcome, and for every sleepless night. This achievement did not come easily, and all of it is by the grace of God.
To my dearest parents, for their support, encouragement and unconditional love that guided me through every step of this journey. This accomplishment is as much yours as it is mine.
To my sisters, my closest friends, who were always there to stand by me.
Your presence in my life means so much to me.

Douaa

Acknowledgment

بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيمِ
“الْحَمْدُ لِلَّهِ الَّذِي هَدَانَا لِهَٰذَا وَمَا كُنَّا لِنَهْتَدِيَ لَوْلَا أَنْ هَدَانَا اللَّهُ ”

First, we thank Allah for giving us the strength and determination to finish this small part of our journey.

We are very grateful to our supervisor, Professor Tarek Bouzid, for his help and advice during this work.

We also thank the members of the committee for accepting to review and discuss our work.

And finally, we thank our family and all those who supported us for their kindness and encouragement.

ملخص

تقدم هذه المذكرة دراسة تهدف إلى تحسين أداء الشبكات اللاسلكية باستخدام الطائرات بدون طيار UAVs ضمن بيئة شبكات الجيل الخامس. تركز الدراسة على مفهوم تقسيم الشبكة الذي يسمح باستخدام جزء من البنية التحتية للشبكة لتلبية احتياجات الخدمات المختلفة. كما تهدف المذكرة إلى حل المشكلات التي قد تواجهها الطائرات بدون طيار أثناء التشغيل، مثل انخفاض طاقة البطارية، أو ازدحام النطاق، أو عدم التوافر المفاجئ، وذلك من خلال دمج طائرات بدون طيار احتياطية في النظام.

صُمم نموذج مقترح يعتمد على نظام متطور يضمن استمرارية الخدمة ويحقق أقصى مستوى من رضا المستخدمين من خلال خوارزميات تختار الطائرة بدون طيار الاحتياطية الأنسب بناءً على شروط مثل سعة البطارية ونوع الخدمات المقدمة، مع ضمان أسعار معقولة للمستخدمين.

تتضمن الدراسة نموذج نظام باستخدام لغة النمذجة الموحدة UML، وتطبيق الخوارزميات المقترحة بواسطة MATLAB لإثبات فعالية الحلول المقترحة مقارنةً بالنظام السابق. أظهرت النتائج أن النظام قد تحسن بشكل كبير في نسبة المستخدمين المتصلين، خاصةً في حالات الطوارئ أو عند زيادة عدد المستخدمين بشكل مفاجئ.

وأخيراً، تساهم هذه المذكرة علمياً في مجال دمج الطائرات بدون طيار مع شبكات الجيل الخامس، وتمثل خطوة لتطوير أنظمة اتصالات مرنة وعالية الكفاءة تخدم المتطلبات المستقبلية في مجالات متعددة.

كلمات مفتاحية : طائرة بدون طيار، الجيل الخامس، شرائح الشبكة طائرات بدون طيار احتياطية، محطة القاعدة، معدل النقل ، الشبكات المدعومة بالطائرات بدون طيار، عملية التسليم

Abstract

This thesis presents a study aimed at improving the performance of wireless networks using unmanned aerial vehicles UAVs within a 5G network environment. It focuses on the concept of network slicing which allows part of the network infrastructure to be used to serve the needs of different services . The thesis also aims to resolve issues that UAVs might face during operation such as low battery, band congestion or sudden unavailability by integrating backup UAVs into the system.

A proposed model was designed based on an advanced system that ensures service continuity and achieves the maximum level of user satisfaction through algorithms that select the most appropriate backup UAV based on conditions such as battery capacity and the type of services provided, while ensuring reasonable pricing for users.

The study includes a system model using the UML activity diagrams and the implementation of the proposed algorithms by MATLAB to demonstrate the effectiveness of the proposed solutions compared to the previous system. The results showed that the system improved much better in the percentage of connected users and their non abandoned, especially in emergency situations or when the number of users increases suddenly.

Finally, this thesis contributes scientifically to the field of integrating UAVs with 5G networks and represents a step for developing flexible and highly efficient communications systems that serve future requirements in multiple fields.

Keywords : UAV, 5G, network slicing, backup UAVs, base station (BS), throughput, UAV-Assisted Networks, handover process.

Résumé

Cette thèse présente une étude visant à améliorer les performances des réseaux sans fil utilisant des drones UAV dans un environnement réseau 5G. Elle se concentre sur le concept de découpage réseau, qui permet d'utiliser une partie de l'infrastructure réseau pour répondre aux besoins de différents services. Elle vise également à résoudre les problèmes rencontrés par les drones en fonctionnement, tels que la batterie faible, la congestion de la bande passante ou l'indisponibilité soudaine, en intégrant des drones de secours au système.

Un modèle a été conçu, basé sur un système avancé, qui assure la continuité de service et atteint un niveau de satisfaction utilisateur maximal grâce à des algorithmes sélectionnant le drone de secours le plus approprié en fonction de conditions telles que la capacité de la batterie et le type de services fournis, tout en garantissant un prix raisonnable pour les utilisateurs.

L'étude comprend un modèle système utilisant le langage de modélisation unifié UML et l'implémentation des algorithmes proposés par MATLAB afin de démontrer l'efficacité des solutions proposées par rapport au système précédent. Les résultats ont montré une nette amélioration du pourcentage d'utilisateurs connectés et non abandonnés, notamment en cas d'urgence ou d'augmentation soudaine du nombre d'utilisateurs. Enfin, cette thèse contribue scientifiquement au domaine de l’intégration des drones aux réseaux 5G et représente une étape dans le développement de systèmes de communication flexibles et hautement efficaces qui répondent aux exigences futures dans de multiples domaines.

Mots-clés : UAV, réseau 5G, découpage de réseau, UAV de secours, station de base, capacité de transmission, réseaux assistés par UAV, processus de transfert.

Table of contents

List of figures

List of abbreviations

B5G	**B**eyond **5G**
BS	**B**ase **S**tation
CP	**C**ontrol **P**lane
eMBB	**E**nhanced **M**obile **B**road**B**and
FR	**F**requency **R**ange
IoT	**I**nternet **o**f **T**hings
LoS	**L**ine **o**f **S**ight
MANET	**M**obile **A**d hoc **NET**work
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
mMTC	**M**assive **M**achine-**T**ype **C**ommunications
NR	**N**ew **R**adio
NFV	**N**etwork **F**unctions **V**irtualization
OSI	**O**pen **S**ystems **I**nterconnection
QoS	**Q**uality **o**f **S**ervice
RAN	**R**adio **A**ccess **N**etwork
SDN	**S**oftware-**D**efined **N**etworking
TCP/IP	**T**ransmission **C**ontrol **P**rotocol / **I**nternet **P**rotocol
UAV	**U**nmanned **A**erial **V**ehicle
UAVHSA	**UAV** **H**ybrid **S**lice **A**ssistance
UAVSA	**UAV** **S**lice **A**ssistance
UE	**U**ser **E**quipment
uRLLC	**U**ltra-**R**eliable **L**ow-**L**atency **C**ommunications
UML	**U**nified **M**odeling **L**anguage
UP	**U**ser **P**lane
VANET	**V**ehicular **A**d hoc **NET**work
WAN	**W**ide **A**rea **N**etwork
WMN	**W**ireless **M**esh **N**etwork
WSN	**W**ireless **S**ensor Network
3GPP	**3rd** **G**eneration **P**artnership **P**roject
5G	**F**ifth-**G**eneration

General introduction

Unmanned Aerial Vehicles (UAVs) are one of the most modern technologies that have begun to play an essential role in supporting and developing telecommunications networks, especially in the development of fifth-generation (5G) networks and the increasing demands for flexible and dynamic networks.

By using these UAVs as units supporting the Radio Access Network (RAN), service coverage can be expanded and stable connectivity can be provided in areas with high density or limited infrastructure.

This thesis focuses on studying and analyzing the use of UAVs in network slicing, with the goal of improving Quality of Service (QoS), providing a more stable and efficient system, ensuring service continuity, and reducing the number of unserved users.

This innovative model relies on the addition of backup UAVs to the previous system. These backup UAVs operate when called in emergency situations, such as low battery level or bandwidth congestion for crowd-sourced UAVs.

The proposed model was validated using simulation tools such as MATLAB, with Excel used for result visualization and data analysis.

This thesis is structured into four chapters:

- **Chapter One:** This chapter explains the evolution of network technologies, with a particular focus on cellular network generations and the challenges faced by modern networks in supporting different devices. It also focuses on 5G and its underlying technologies, such as Network Function Virtualization (NFV) and Software Defined Networking (SDN), as well as the concept of network slicing and UAVs.
- **Chapter Two:** This chapter provides a critical analysis of previous studies on incentive-supported UAV systems, focusing on their gaps and challenges, highlighting the need to propose a new system that enhances stability, efficiency, and user satisfaction in 5G.
- **Chapter Three:** This chapter presents a proposed model that integrates crowd-sourced UAVs and backup UAVs to ensure service continuity and reduce interruption and down times. It also presents algorithms and UML activity diagrams and methods for UAV selection, achieving good QoS, and improving pricing policies to ensure fairness for users and crowdsourced UAVs.
- **Chapter Four:** This chapter presents the practical aspect of the study, which is the core part that showcases the benefits of the proposed improvements. We focused on simulation tools such as MATLAB to test system performance, and Excel to convert the results into illustrative charts.

Chapter

1

Background and Core Technologies of 5G Networks and UAVs

1.1 Introduction

Today, as network technologies evolve, they become increasingly complex, driven by increasing demand for greater capacity, improved performance, and flexible connectivity. This evolution is evident in the evolution of cellular network generations, each characterized by significant innovations. Modern networks face the challenges of supporting a variety of devices, each with unique requirements and priorities. To meet these challenges, networks must optimize resource allocation and deliver high quality services in different contexts. In this chapter, we discuss fundamental concepts such as cellular network generations, network layers, wireless communication systems, and wireless access technologies.

We then move to Fifth-Generation (5G) cellular networks, focusing on their architecture and enabling technologies such as Network Function Virtualization (NFV) and Software Defined Networking (SDN). Network slicing is a key topic, essential to meeting the diverse needs of modern applications and devices. The comprehensive analysis presented in this chapter lays the foundation for understanding the transformative role of 5G technology and emerging innovations such as the integration of unmanned aerial vehicles (UAVs) into modern network systems.

1.2 Networks

The Internet has proven its importance in various fields as the largest and most influential network and has become an integral part of our modern lives. This chapter introduces the basic concepts of networks and their types, providing a foundation for understanding network segmentation. It also explains the crucial role of UAVs in developing network capabilities.

1.2.1 Network protocol stack review

Networks generally consist of basic layers, from the physical layer to the application layer. Over time, various alternative models have been proposed, most notably the seven layer Open Systems Interconnection (OSI) model and the four-layer Transmission Control Protocol / Internet Protocol (TCP/IP) model as shown in Figure 1.1. The network access layer plays a crucial role in establishing connectivity between communicating nodes. This thesis focuses on the physical layer, since UAV integration primarily concerns the wireless aspect of the network.

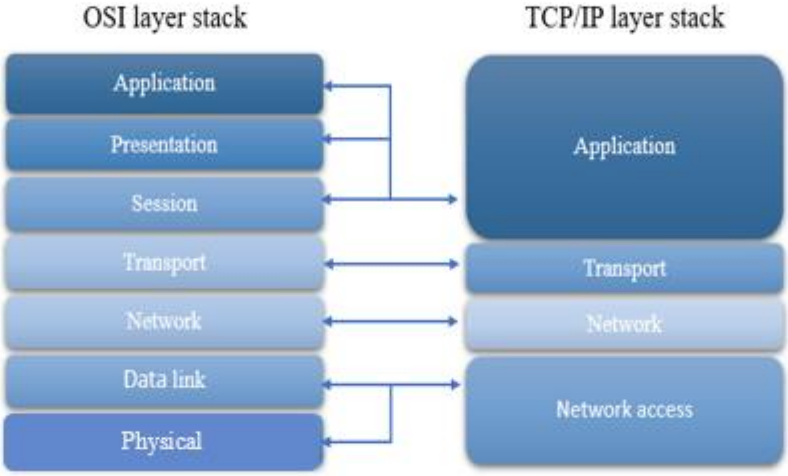


Figure 1.1 : OSI layers vs TCP/IP layers

a. Cellular network layers

The Cellular Network layer is a model specifically designed for wireless communications, unlike the OSI model, which provides a general framework of seven distinct layers for network protocols. Due to architectural and infrastructure differences, the traditional overlay scheme is not directly applicable to modern networks. While the application and physical layers remain fundamental, other layers can be redefined or combined within different functional layers.

In cellular networks, two separate protocol stacks are used, as shown in Figure 1.2, to optimize their efficiency, scalability and support for user mobility [1].This division ensures that the specialized characteristics of cellular networks are effectively accommodated, with the protocol stack comprising two distinct planes. The Control Plane (CP) handles signaling and control functions such as session management, mobility control, and radio resource allocation. The User Plane (UP) is responsible for efficiently transmitting user data traffic like browsing and streaming. Separating CP and UP in the 5G architecture enhances performance and provides greater flexibility in scalability and Quality of Service (QoS) management.

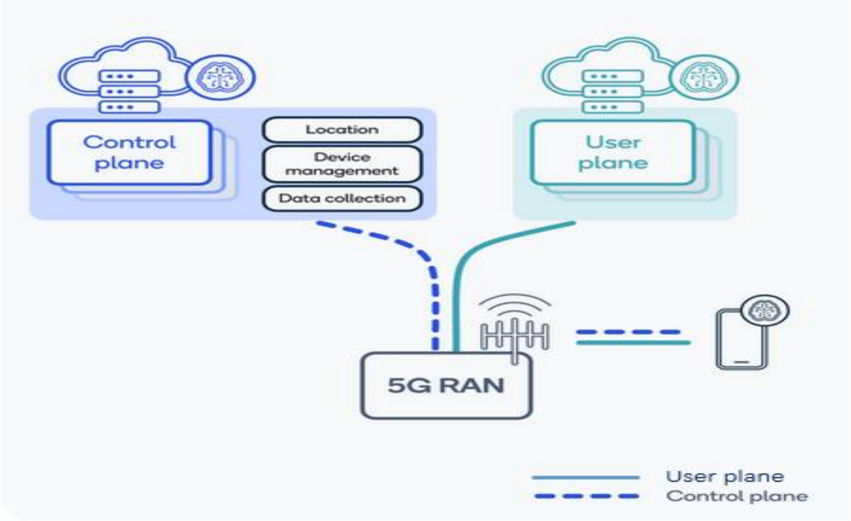


Figure 1.2:The 5G protocol stacks (User plane and Control plane) [2]

b. Detailed protocol stack

Compared to the Long Term Evolution (LTE), the 5G architecture encompasses an updated stack as it becomes more virtualized, relying on NFV and SDN. The 5G New Radio (NR) stack addresses the unique challenges and use cases presented by the next generation of wireless networks. For instance, we see the focus on segmenting layers into multiple sub layers to accommodate for the physically distributed hardware deployment and network flexibility as shown in Figure 1.3.

In 5G NR, the protocol stack undergoes significant modifications see Figure 1.3 to meet the evolving requirements of wireless mobile communication. This revised stack introduces a more detailed hierarchy with distinct layers and sub layers, aiming to support a wide range of services, including high speed data transfer, low latency communication and extensive Internet of Things (IoT) device connectivity.

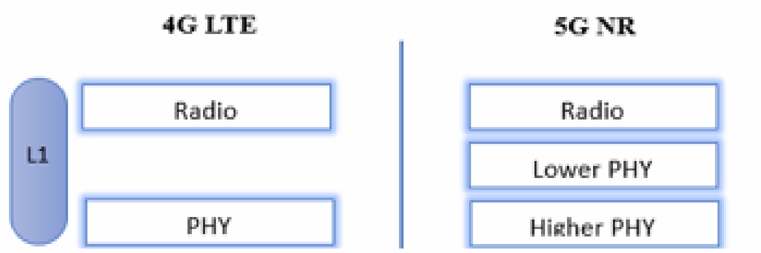


Figure 1.3: 4G LTE and the revised 5G NR in physical layer

1.2.2 Cellular networks

Cellular networks represent an advanced and complex form of networking, integrating multiple technologies. Their large scale and the mobility of users necessitate handover mechanisms, efficient resource management and other techniques to ensure consistent coverage and sufficient capacity.

a. Notable involved organizations

Before examining cellular 5G, it is important to highlight the essential organizations and standards institutions that have advanced cellular network technologies:

- **Third Generation Partnership Project (3GPP)**:
  Established in 1998, 3GPP is a global collaboration of telecom standards organizations, including ETSI and Alliance for Telecommunications Industry Solutions (ATIS), that develops technical specifications for mobile networks for example 2G, 3G, LTE, 4G, 5G. It focuses on radio access technologies, core network architectures, protocols and security [3].
- **European Telecommunications Standards Institute (ETSI)**:
  Founded in 1988, ETSI develops standards to ensure interoperability and efficiency in telecommunications, IoT and Beyond 5G (B5G). It collaborates with 3GPP on mobile networks and leads initiatives like NFV, Intelligent Transportation Systems (ITS) and Vehicle-to-Everything (V2X) communication to enhance connectivity and innovation [4].
- **Open Networking Foundation (ONF)**:
  Established in 2011, ONF promotes SDN and open standards. It introduced OpenFlow and expanded into initiatives like broadband mobile networks and 5G deployment, driving network openness and virtualization [5].
- **International Telecommunication Union (ITU)**:
  Founded in 1865 and part of the UN since 1947, ITU develops global telecom standards and manages spectrum allocation for mobile communications. Its work supports international cooperation and spectrum management critical to cellular networks [6].

b. Evolution of cellular generations and release

Mobile technology evolves approximately every decade, with each generation introducing significant advancements. 3GPP drives this evolution through regular "releases" that refine aspects like radio parameters, core networks, authentication and security we find [3]:

- **Release 14 (2017):** Enhanced 4G LTE with higher data rates and efficiency, setting the stage for 5G.
- **Release 15 (2019):** Established the initial 5G NR framework, supporting Enhanced Mobile BroadBand (eMBB), Massive Machine-Type Communications (mMTC), Ultra-Reliable Low-Latency Communications (uRLLC) and enabled the first 5G commercial deployments.

- **Release 16 (2020):** Introduced services like V2X and extended radio spectrum support, expanding 5G's capabilities.
- **Release 17 (2022):** Advanced 5G to operate up to 71 GHz, optimized Multiple Input Multiple Output (MIMO) technology and improved resource allocation.
- **Release 18 (2023–2024):** Focus on 5G-Advanced enhancements, including Artificial Intelligence/Machine Learning (AI/ML) integration, satellite connectivity, RedCap IoT support and early 6G research.
- **Release 19 (2024–2025):** Expands 5G-Advanced with terahertz THz exploration, reconfigurable intelligent surfaces (RIS), quantum-secure cryptography and Extended Reality (XR), Augmented Reality / Virtual Reality (AR/VR) optimization, Lays groundwork for 6G.
- **Release 20 (2025–2026):** Initiates 6G standardization, targeting terabit data rates, sub-millisecond latency, sustainable networks and AI driven digital twin integration.

1.2.3 Other wireless networks

5G is the primary focus of this work due to its innovative nature and its role in influencing future B5G networks [7]. Cellular networks are emphasized for their adaptability and broad range of applications. However, given the heterogeneous nature of modern cellular systems, it is essential to address other network types that integrate with 5G and B5G frameworks.

Figure 1.4 presents a classification of wireless networks based on defined and variable coverage ranges. Cellular networks fall under the Wide Area Network (WAN) category, connecting cities and countries on a large scale. In contrast, ad hoc networks operate without fixed infrastructure, allowing their size and range to dynamically adjust based on user mobility and connections.

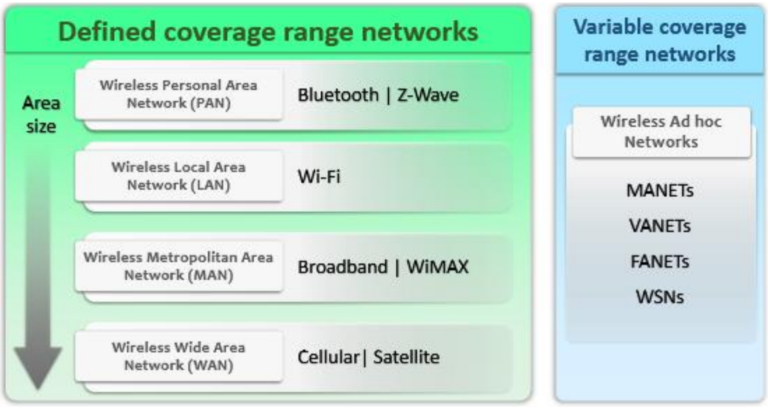


Figure 1.4:Classification of wireless networks according to range

Ad hoc networks Ad Hoc are among the most important types of wireless networks, as shown in Figure 1.5. Wireless Ad Hoc networks are classified into three main types Wireless Mesh Networks (WMNs), Mobile Ad hoc NETwork (MANET) and Wireless

Sensor Networks (WSNs). These networks rely on direct communication between nodes without the need for fixed infrastructure. MANETs are a dynamic type that includes mobile devices and two specialized types branch out from them Vehicular Ad hoc NETwork (VANETs) used between vehicles and FANETs for UAVs. WMNs provide extended coverage through multiple nodes, while WSNs are used to monitor environments through sensor nodes that send data to collection centers. This classification reflects the diverse applications of Ad Hoc networks in advanced communications of its target users. Additionally, several other wireless network types are notable for their distinct features and applications:

- Wireless Mesh Networks (WMNs) [8]
- Wireless Sensor Networks (WSNs) [9]
- Satellite Networks [10]
- Device-to-Device (D2D) Networks [11]

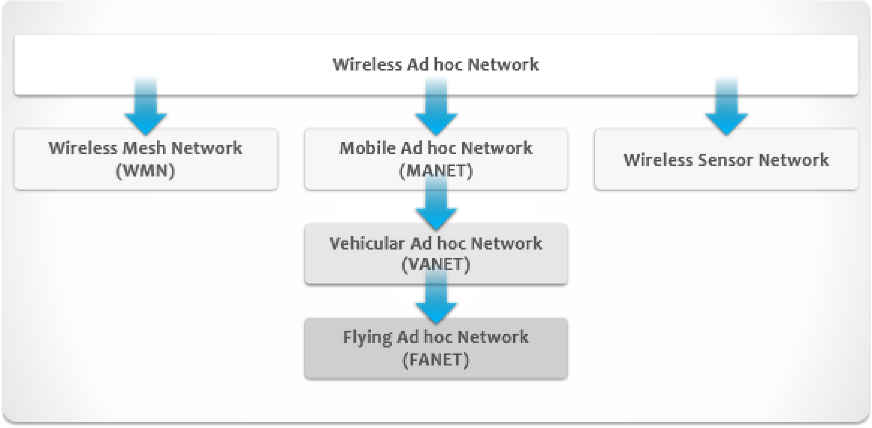


Figure 1.5:Ad hoc network types

1.3 Electromagnetic waves

The electromagnetic spectrum is the primary medium for cellular networks, facilitating mobility and wireless communications. This is becoming increasingly important with the emergence of UAVs and vehicles as major users of cellular networks.

The electromagnetic spectrum encompasses various frequencies that are critical for wireless communications. Low-frequency waves such as radio waves are characterized by their long wavelengths and low energy, while their energy increases with higher frequency, reducing distance and propagation. Radio spectrum use is concentrated in three main categories low frequency up to 300 MHz, which provides good coverage and is used for radio navigation, aviation and maritime navigation, medium frequencies between 300 MHz and 30 GHz, which are used for cellular communications, Wi-Fi networks and space systems such as GPS, Ultra-high frequencies above 30 GHz offer high speeds but suffer from limited deployment and are vulnerable to obstructions. 5G and beyond networks leverage this diversity to meet user needs by flexibly combining high and low bands. The 5G NR spectrum is divided into two ranges:

- **Frequency Range 1 (FR1)**
  From 410 MHz to 7.125 GHz, suitable for cellular communications, balancing range and performance. It is intended for wide-area coverage with good penetration through walls and buildings.
- **Frequency Range 2 (FR2)**
  24.25 GHz to 71 GHz, focusing on mm-Waves with high capacity but limited range. FR2 is further divided into FR2-1 and FR2-2 for more granular use.

High VS Low

- **Low Frequencies**
  Provide long range and wide coverage, making them suitable for remote areas and low-density infrastructure. They have limited data capacity and penetrate walls and buildings very efficiently, which is compatible with FR1.
- **High Frequencies**
  Have short range and require a high density of towers or nodes to achieve coverage. They support high data speeds and greater capacities, making them ideal for advanced applications, but are affected by obstructions and require direct LoS. This is compatible with FR2.

1.4 Radio access technologies (RAT)

To handle the diverse range of 5G users, multiple advanced radio access technologies RATs are employed. These include protocols like Wi-Fi, WiMax, Bluetooth, Zigbee and others that rely on wireless communications. NR is the core radio technology for 5G, enabling high data rates, ultralow latency and enhanced network performance. Key technologies include:

- **mm-Wave**
  The mm-Wave spectrum already utilized by technologies like WiMax and WiGig offers high data rates but requires small cell deployments in urban areas due to its short range and susceptibility to attenuation. Line-of-Sight (LoS) is crucial for maintaining signal integrity in mm-Wave communication.
- **Massive MIMO**
  This technology uses a large number of antennas over 64 to improve spectral efficiency, signal quality and multi-user connectivity. It enhances coverage and throughput by using beamforming which directs the signal towards specific users improving Signal-to-Interference-plus-Noise Ratio.

- **Beamforming**
  This technique adjusts signal phase and amplitude to focus energy in a specific direction, improving efficiency and reducing interference. It is especially useful when combined with Massive MIMO for mm-Wave communication.

1.5 Considered end users

The diverse range of network users and their varying needs pose significant challenges for the design and implementation of modern networks. These User Equipment (UEs) include:

- **Computers, Smartphones, and Tablets**
  These common devices require high data rates for multimedia consumption, making them primary beneficiaries of 5G advancements.
- **UAVs**
  UAVs are not only users of cellular networks but also serve as network assistants. They can act as aerial relays, enhance network coverage, assist in disaster recovery and monitor critical infrastructure.
- **IoT Devices**
  IoT devices are characterized by low power consumption and energy efficiency. They range from agricultural and industrial sensors to smart home devices and health sensors, each facing communication and throughput challenges due to power constraints. [12]
- **Vehicles**
  Autonomous vehicles and their communications V2X, Vehicle-to-Vehicle (V2V) are essential for the success of smart cities and transportation automation. They demand low latency, real-time processing and adaptable network topologies.

1.6 The 5G cellular network

Cellular networks are constantly evolving to provide higher speeds and greater capacity. 5G marks a transition toward heterogeneous networks with goals of ultra-fast connectivity, a large number of connected devices and low latency.

5G Requirements:

- High throughput in dense areas.
- Latency below 1 ms.
- A large number of connected devices (100 times more than 4G).
- Near-universal coverage and 90% reduced power consumption for low-power devices.

The three main use cases for 5G are:

- **eMBB** for high throughput.
- **uRLLC** for low latencies
- **mMTC** for large device numbers

1.6.1 Key technologies in 5G

The 5G technologies represent a transformative leap in telecommunications, driven by the integration of advanced innovations such as Network Slicing and Multi-access Edge Computing (MEC).

Network Slicing enables the infrastructure to be divided into virtual segments tailored to specific application needs such as data speed or latency while MEC minimizes delays by processing data closer to users, ensuring real time responsiveness. Complementing these, SDN and NFV play essential roles, SDN decouples network control from data forwarding, enabling centralized, dynamic management, while NFV transforms traditional hardware based functions for example routers and firewalls into software services operating on standard hardware. This synergy reduces costs, accelerates service deployment and empowers 5G to efficiently support futuristic applications like autonomous vehicles and the IoT with seamless scalability and adaptability.

1.6.2 5G architecture

The 5G network consists of three main components:

a. **Core Network**: It manages essential functions such as user mobility, session establishment, termination and data routing.

b. **Transport Network**: This network connects the core to the radio access network and enables data transmission with low latency and high capacity. It provides flexible and dynamic resource allocation through the use of SDN.

c. **Radio Access Network (RAN)**: It consists of components such as Radio Unit (RU), which handles the conversion of radio signals, Distributed Unit (DU), which processes lower layer signals and Centralized Unit (CU), which manages control and coordination functions. These units enhance network management, especially in high frequency bands such as millimeter waves.

1.7 Network slicing

The concept of network slicing allows for the division of a physical network infrastructure into multiple isolated virtual networks. Each slice is designed to meet the specific needs of particular applications, offering distinct performance parameters, resource allocations and service characteristics. This process relies on technologies such as virtualization SDN, NFV as well as RAN resources and orchestration, which are essential elements in 5G networks.

1.7.1 Overview of network slicing

Network slicing divides a physical network into instances of distinct virtual networks. Each slice is dedicated to a specific application or service, this means that it offering customization of resources and performance. This approach requires the virtualization of resources, the use of SDN, NFV, RAN resources and orchestration to ensure optimal operation. As shown in the Figure 1.6.

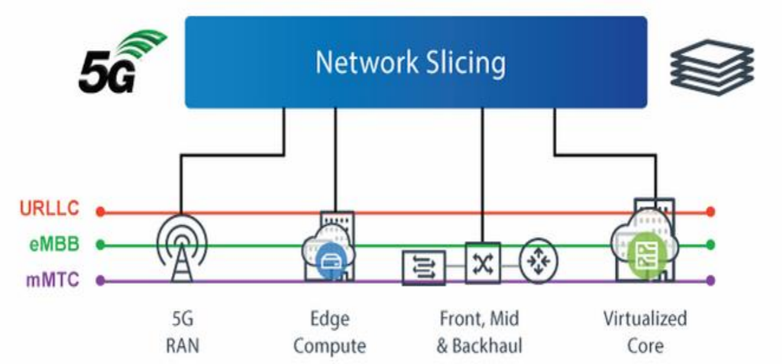


Figure 1.6: Network Slicing in 5G Architecture [20]

Network slicing requires an end-to-end (E2E) architecture that spans the core network, transport network and RAN. Each component must be virtualized and controlled to ensure isolation and efficient resource allocation to each slice. Orchestration is crucial to manage resources and ensure effective communication between the slices.

- **Slicing at the RAN:** Partitioning radio resources such as frequency bands in the RAN is essential to ensure that each slice has the resources necessary to meet its coverage and performance needs.
- **Slicing at the Core:** Core network slicing involves assigning specific functions and routing policies to each slice, allowing isolated management of traffic.
- **Slicing at the Transport:** The transport network ensures that slice traffic is handled optimally through data flow management via SDN, allowing for the allocation of bandwidth, latency and routing.
- **Slicing Orchestration:** Centralized orchestration via a slice manager is necessary to oversee the entire lifecycle of slices from creation to decommissioning, while applying performance and QoS policies.

1.7.2 Slice defining attributes

The attributes of slices can be customized based on the specific needs of each application. Among the adjustable parameters are:

- **Throughput:** The throughput is adjusted according to the user’s needs with an emphasis on optimizing transport and RAN resources to support different throughput rates.
- **Latency:** Latency is reduced by prioritizing packets in transport and using MEC for applications that require low response times.
- **Reliability:** Reliability focuses on stable connectivity, particularly in industrial environments where radio conditions can be controlled.
- **Energy Efficiency**: Energy efficiency is particularly important in mMTC, with devices needing low power consumption while being resilient to interference.
- **Capacity**: The mMTC network must support a large number of devices by efficiently using the available spectrum and optimizing frequency reuse schemes.
- **Availability**: Availability is measured by the time a slice provides its services without interruption, requiring redundancy mechanisms and proactive maintenance.
- **Packet Size**: Packet size is optimized according to the slice's needs eMBB users can benefit from larger packets, while uRLLC users prefer smaller packets to reduce latency.

1.7.3 Network slicing and QoS

- QoS is a method used to manage and prioritize network traffic to guarantee specific performance such as low latency and maintaining bandwidth.
- Network slicing takes this further by creating dedicated virtual networks, each with its own resources and characteristics. Unlike QoS, which optimizes a single infrastructure, network slicing offers separate virtual networks for each particular need while integrating QoS to ensure quality.

1.8 UAVs

UAVs have emerged as transformative tools across various industries, revolutionizing applications from agriculture to disaster response. In the field of computer science, they introduce challenges and opportunities such as optimizing routing algorithms and maximizing resource utilization. Initially developed for military purposes, UAVs have evolved into versatile, widely commercialized assets in both civil and commercial sectors.

1.8.1 UAV types and classification

UAVs are designed with varying types based on their intended applications. Consumer UAVs, for example are highly agile, capable of sharp turns and rapid altitude changes, while larger fixed wing UAVs prioritize efficiency and long distance coverage over maneuverability. Vertical Take-Off and Landing (VTOL) UAVs, add versatility for operations in confined spaces like surveillance and delivery with hovering and vertical flight capabilities. The type of UAV significantly influences its suitability for specific tasks, necessitating a clear understanding of classifications and capabilities before addressing their contributions. Figure 1.7 illustrates common UAV types. UAVs are often categorized by Size, Weight and Power SWaP or by flight mechanisms such as fixed wing, rotary wing or hybrid designs [13]

Figure 1.7: Different classes of UAVs based on wing types

1.8.2 UAV applications and communication

UAVs are increasingly utilized in telecommunications networks to enhance performance and deliver advanced services. They play multiple roles, including serving as temporary BS, functioning as mobile wireless BS and acting as wireless signal converters to relay signals between BS devices. Additionally, UAVs can operate as MEC nodes, leveraging MEC technologies to provide more efficient edge services. Beyond these technical functions, UAVs offer practical applications such as improving quality and efficiency, expanding coverage in remote areas and supporting emergency response and public safety. Furthermore, they are used for monitoring, surveillance and the transportation of information and goods, making them versatile tools in modern telecommunications.

1.9 Summary

This chapter provides an overview of advanced network technologies, focusing on the role of the electromagnetic spectrum, management of high and low frequencies and wireless access techniques. It highlights the importance of SDN and NFV in the architecture of 5G networks and their integration with core network components and the RAN. The significance of these technologies, along side MEC in enabling Network slicing is explained with reference to their evolution in sixth-generation (6G) networks and the increasing integration of artificial intelligence. The chapter also reviews the classification, applications and challenges of UAVs, as part of the design of future flexible and dynamic networks. In the next chapter we will review previous studies on incentive-supported UAV systems that support network slicing and offer some solutions to many of the problems faced by modern networks.

Chapter

2

Literature review and previous work critique

2.1 Introduction

In the previous chapter, we discussed advanced networking technologies with a focus on spectrum management and key elements such as SDN, NFV and MEC in 5G networks and their evolution in 6G networks. It also highlighted the role of UAVs in building dynamic networks.

This chapter also provides a comprehensive review and critical analysis of previous studies on incentive supported UAV systems that support network slicing. This section focuses on reviewing key technologies such as 5G networks, UAV integration, network slicing techniques and crowdsourcing based incentive systems. It also aims to identify gaps in existing studies and highlight some challenges they face to demonstrate the need for a proposed system that ensures system reliability, stability and user satisfaction in 5G and post-5G environments.

2.2 A work involving 5G

5G networks are a major development in modern communications, relying on SDN and NFV to enable the system to meet user requirements. 5G network slicing allows for resource allocation to match the specific requirements of different applications. However, these networks still face challenges related to efficient spectrum management and the integration of heterogeneous network infrastructures. Key use cases for 5G networks include eMBB, uRLLC and mMTC, which form the basis for future applications such as the Industrial IoT and autonomous vehicles. In the IoT space, sensors are widely used in various fields. It is estimated that the number of sensors will increase over time, becoming a huge number which poses a significant challenge in collecting the massive amounts of data from them. IoT data collection technologies require low power consumption, low delay and high reliability. UAVs with wide coverage and high mobility provide new opportunities for IoT data collection. UAV-assisted data collection features high speed, flexibility and low cost. In addition, UAVs can collect data in close proximity to sensors, significantly reducing IoT power consumption. The combination of UAVs and IoT facilitates timely and efficient data collection, especially in complex, harsh or remote environments [12].

2.3 UAVs in networks

UAVs are essential components in the development of modern wireless networks, playing a strategic role in improving coverage and enabling dynamic communications. These roles include communication models such as UAV-to-device and device-to-device. UAVs are used in practical applications such as restoring communications in emergencies, providing internet service in remote areas and supporting smart grids through MEC. Furthermore, case studies such as the use of UAVs in smart cities and agriculture are analyzed to demonstrate their effectiveness in different environments [14]. Software transformation in UAV networks demonstrates how technologies such as SDN and NFV can enhance the efficiency and flexibility of UAV networks. UAVs have also become an important component of modern network architectures. UAVs can be controlled, tasks assigned and data rerouted flexibly and intelligently via software without the need to modify the physical architecture. The study also highlights the role of these UAVs in complex environments such as natural disasters or remote areas.

2.3.1 Issues and challenges of UAVs

UAVs face several key challenges that impact their efficiency and performance. First, limited endurance and energy present a major constraint due to current battery technology which limits flight duration and mission range. Second, coordination and control among multiple UAVs require advanced algorithms to avoid collisions and optimize task and route distribution. Privacy and safety also pose significant challenges as UAVs are vulnerable to cyberattacks, privacy concerns during surveillance and risks in crowded areas, necessitating collision avoidance systems. Limited payload capacity and processing power are also challenges, requiring improvements in lightweight materials and distributed processing to expand application ranges. Interference and spectrum allocation issues need to be addressed to avoid interference with other networks and ensure reliable communication. Finally, regulations play a crucial role in UAV adoption, as stringent legislation in some countries may hinder development, requiring effective air traffic management systems to ensure integration with manned UAV.

2.4 UAVs in 5G

UAVs are a strategic component in enhancing 5G networks, being used to provide temporary coverage in disaster situations, support remote areas and improve dynamic communications in smart cities by integrating them into different network layers such as the RAN as mobile access points and the core network through technologies such as SDN and NFV to ensure dynamic data control, along with MEC to reduce latency in critical applications. Network slicing technology is also used to allocate independent resources to each task, ensuring QoS and isolation between applications. However, these solutions face challenges such as power limitations, interference management with ground networks, coordination between multiple UAVs and regulatory restrictions. Studies such as [15] highlight the role of UAVs in enhancing network resilience by providing MEC resources which contributes to improving the QoS provided to end users. This is achieved through network slicing techniques that enable meeting the requirements of various applications, particularly in terms of reducing response time, increasing reliability and providing adequate bandwidth. Other studies have also demonstrated the effectiveness of integrating UAVs with edge computing and network slicing but further improvements in energy efficiency, security and wireless resource management remain necessary to enhance their role in future networks.

2.5 Network slicing

Network slicing technologies are essential components in the development of 5G and B5G networks used to divide infrastructure into independent slices to meet diverse requirements. These technologies include E2E architectures spanning the RAN, core network and transport networks with a focus on resource isolation to ensure QoS for each slice. They are also used in advanced applications such as slices for the IoT,V2X communications and augmented virtual reality. However, these technologies face several challenges, including dynamic resource allocation, slice coordination and security vulnerabilities. A focus is on integrating UAVs to enhance flexible and dynamic coverage through the deployment of ad hoc aerial network slices. The paper [16] discussed the concept of network slicing in 5G networks, explaining how dedicated logical networks can be created on the same infrastructure to provide diverse services tailored to the needs of each application. The technology relies on SDN and NFV to provide flexibility and programmability. The study also highlights challenges such as slicing isolation, resource management and QoS assurance.

2.6 Incentive based work

Incentive models in wireless networks focus on encouraging users and devices to participate in service provision. These include competitive auction systems for spectrum allocation systems that prioritize reliable UAVs and incentives to ensure transparency and security. Additionally, crowdsourcing models are used to motivate UAVs to expand coverage through financial rewards or micropayments. Authors of the study in [17] review the latest theoretical developments, applications, system implementations and empirical studies of incentive strategies used in participatory sensing by increasing the reliability of sensor data in participatory sensing systems and reputation schemes.

2.7 Crowdsourcing and crowdsourced work

Crowdsourcing networks rely on the participation of individuals or devices to provide network services such as expanding coverage via crowd-sourced UAVs or collecting environmental data in smart cities. These models are effective in reducing infrastructure costs, but they face challenges in ensuring data integrity and the fair distribution of rewards. A practical example of this is IoT projects in remote areas such as Project Loon, where UAVs are used to provide connectivity in resource limited environments. The paper [18] illustrates how crowdsourcing has evolved as an effective tool for leveraging online contributions from individuals to perform various tasks from data collection to software development. The study also discussed task assignment methodologies. It also reviews the various platforms that support crowdsourcing and how the design of these platforms affects the effectiveness of task execution.

2.8 Critique of incentive-based crowdsourced UAV-assisted network slicing

Crowdsourcing is a modern tool that enables companies and organizations to collect data and perform tasks at a low cost, often offering compensation or incentives to encourage participation. This approach can be applied to enhance network support through crowd-sourced UAVs.

The work in [19] introduces two UAV-assisted network slicing systems UAV Slice Assistance (UAVSA) is a system where only the UAVs can serve users and UAV Hybrid Slice Assistance (UAVHSA) users can fall back to the Base Station (BS) if no UAVs are present and designed to optimize user satisfaction and data delivery. By leveraging UAVs and hybrid UAV-BS approaches, the study demonstrates their impact on throughput and slice satisfaction, especially at high frequencies.

2.8.1 Overview of the previous study

The previous study in [19] aims to ensure high throughput through the use of UAVs in densely populated areas such as fairs and festivals or to improve connectivity for users who suffer from low data rates.

This strategy seeks to achieve cost-effective and efficient solutions while ensuring high-quality services for users, even under the most challenging conditions. However, several problems still exist that in turn reduce the QoS for both the user and the system. This led to the proposal of complementary solutions to this study which will play a significant role in addressing these problems through the use of backup UAVs for the system which we will discuss in the coming chapters.

2.8.2 System description

The research presents an incentive-based system for network slicing using UAVs to enhance coverage and efficiency in 5G and beyond networks. Crowd-sourced UAVs are utilized to provide high-speed, low-latency services for applications such as eMBB and uRLLC, integrating with BSs in a hybrid model to ensure continuous connectivity. UAV pricing is dynamically determined based on demand and energy levels with incentive mechanisms in place for UAV owners. In parallel, BSs handle load and resource distribution through energy management and service prioritization. Simulations demonstrated improvements in user satisfaction, particularly in congested areas, while reducing costs through the use of Crowd-sourced UAVs, making this an innovative solution for network slicing with a focus on flexibility and cost efficiency [19]. The Figure2.1 also shows the system design.

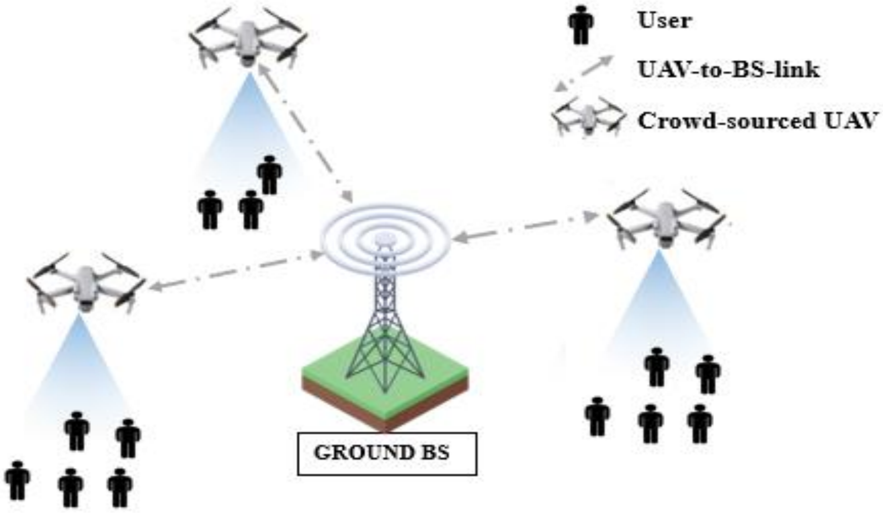


Figure 2.1: Previous system presentation

2.8.3 Issues

Even with the many advantages presented by this study as mentioned in the previous part of this chapter, several gaps have been identified that could lead to certain issues. Among the most notable of these gaps are challenges related to QoS, which negatively impact the user experience and may result in user dissatisfaction in some cases. These issues include:

2.8.3.1 Initial problem and proposition

At the beginning of the process, if no crowd-sourced UAVs were available in the system, the user would be redirected to the BS for service provided that the hybrid mode was enabled. Otherwise, the user would be abandoned.

The proposed solution involves deploying backup UAVs within the system to serve the user instead of crowd-sourced UAVs, while maintaining a fixed cost. This approach ensures consistent service delivery to users without abandonment, enhancing system efficiency and user satisfaction.

2.8.3.2 Second problem and proposition

When the battery level of the crowd-sourced UAV drops while serving a user, it results in the user being abandoned which poses a challenge to service quality and continuity. The proposed solution involves selecting the optimal backup UAV UAV_{sk} from the system based on two factors important. Firstly, it must be capable of providing services equal to or better than those offered by the primary crowd-sourced UAV. Secondly, its battery level must be at least 70% to ensure uninterrupted service. The backup UAV is launched when the crowdsourced UAV battery reaches a critical state, thereby replacing it before it leaves and ensuring no down time for the user.

A seamless handover process is employed to transfer the users from the crowd-sourced UAV to the backup UAV. Once the backup UAV completes its task, it is returned to the system for future use. This approach enhances system efficiency and ensures user satisfaction.

2.8.3.3 Third Problem and proposition

When the crowd-sourced UAVs experience congestion due to bandwidth consumption, they become unable to accommodate additional users. In the event of new users arriving under such circumstances and if the hybrid mode is enabled, the new users are directed to the BS for service provision.

The proposed solution to address this issue involves the BS searching for a suitable working backup UAV within the UAV_{worker} list to serve the new user. If no working backup UAVs are available in this list, the BS proceeds to search for a suitable backup UAV within the $\text{UAV}_{\text{system}}$.

This solution represents a significant turning point in the project, aiming to minimize the loss of new users and ensure the provision of sustainable and efficient services, even under system congestion.

2.8.3.4 Final problem and proposition

If a crowd-sourced UAV abandons a user during service delivery, the system searches for another suitable crowd-sourced UAV to serve the affected users. If no suitable -UAV is available and the hybrid mode is enabled, users are redirected to the BS to complete their service. However, if the hybrid mode is not enabled, users are abandoned which can diminish the system's credibility.

To address this issue and ensure seamless service continuity a solution has been proposed where a standby UAV from the $\text{UAV}_{\text{system}}$ is immediately summoned when a crowd-sourced UAV abandons a user. Simultaneously, the system continuously monitors the availability of either a suitable crowd-sourced or backup UAV. If no suitable crowd-sourced UAV is found, the users are connected to a backup UAV from the $\text{UAV}_{\text{system}}$ to maintain service continuity. This process is elaborated in Function 3 in the next chapter.

2.9 Overview of the wireless channel

This part is essential for understanding how a wireless network works and is used to simulate the network environment and analyze the performance of the previous system. It is particularly useful when integrating UAVs as an enabler for improving coverage and QoS. The model includes consideration of various factors affecting signal transmission between transmitting and receiving points such as path loss, LoS probability and penetration loss through obstacles such as walls. The received signal strength is calculated based on device and environmental characteristics, including transmission power, antenna gains and cable losses. The model also addresses the differences between the frequency bands used in 5G networks, addressing FR1 and FR2 and analyzing their impact on coverage, transmission speed and resistance to environmental obstacles. Additionally, it explains how to calculate the throughput per user using a formula derived from 3GPP standards, which depends on several technical factors such as the modulation rate, coding rate and number of effective data bits.

The overall objective of this model is to provide a precise framework for analyzing the performance of the proposed system under various environmental conditions and to determine the role of UAVs in enhancing signal quality and providing better coverage to users, especially in areas with high density or poor coverage. For more details see [19], note that the current study relies on the same calculation steps mentioned in the previous study [19] because it is considered a complementary study. The Figure 2.2 also shows UAV aided systems representation where the distances and heights highlighted are critical in the calculations.

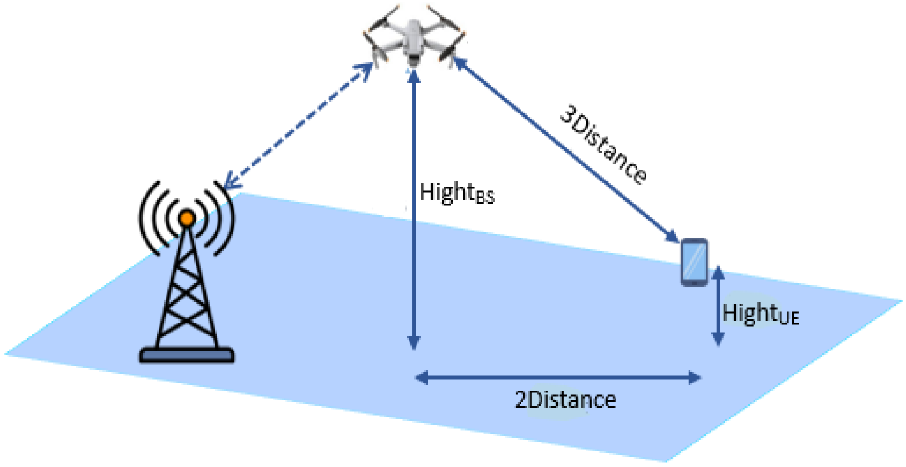


Figure 2.2: UAV aided systems representation

2.10 Summary

This chapter presented the literature related to 5G networks, the integration of UAVs with network slicing technologies and incentive systems with a focus on incentive models to enhance the efficiency of UAVs in environments with limited resources. This study identified some gaps that necessitate the development of innovative solutions to ensure service continuity and maintain performance quality.

The analysis highlighted the critical challenges faced by UAV-assisted network slicing systems. Among the identified gaps we highlight the limited guarantees for QoS and inadequate strategies to address congestion or UAV unavailability. Incentive-based systems Utilizing backup UAVs and dynamic pricing offered solutions to these issues, ensuring service continuity, enhancing user satisfaction and improving resource utilization.

In conclusion, the reviewed literature provides a foundation for the proposed incentive-based UAV-assisted network slicing system. This chapter justifies the need for advanced solutions to enhance system reliability, efficiency and scalability in 5G and beyond environments, paving the way for the development and evaluation of innovative methodologies in the subsequent chapters.

Chapter

3

Incentive-Based Crowdsourced UAV-Assisted Network Slicing with backup UAV Support

3.1 Introduction

The use of UAVs in network slicing environments using 5G technologies has revolutionized the way network services are delivered, especially in scenarios with high user density and limited infrastructure. This solution has been an effective solution for providing flexible network coverage. However, traditional UAV systems have faced significant challenges such as limited battery life and bandwidth congestion which can lead to service interruptions for users, negatively impacting their experience as discussed in previous chapters. To address these challenges, this chapter presents an effective system model that integrates the operation of crowd-sourced UAVs with emergency backup UAVs. The proposed system ensures service continuity and reduces the possibility of interruptions for users by enhancing network stability. The backup UAVs will play a key role in this system, acting as backups in emergency situations, such as the sudden stop of crowd-sourced UAVs or the previously mentioned low battery and full bandwidth. This chapter also explores the design of the proposed system and its components, as well as the proposed algorithms and Unified Modeling Language (UML) activity diagrams models highlighting how to maintain the QoS delivery while improving the system's operational efficiency. It also presents improved pricing strategies to ensure fair profitability for users.

3.2 Motivation

Considering the issues highlighted in the previous chapter on the work of [19], this chapter will present our solution. The main reason is to overcome the problems associated with the unavailability of crowd-sourced UAVs in emergency situations such as low battery or severe bandwidth congestion, which significantly reduces the QoS provided to users. In response to these challenges, backup UAVs solutions have been developed as a strategic means to ensure service continuity and maintain network performance under unstable conditions. These backup UAVs play an essential role as they can intervene immediately in emergencies such as low battery or bandwidth of UAV is full. The need for these UAVs increases particularly in two additional important situations First when UAVs are unavailable in an area, either due to poor deployment or delayed response times, leading to coverage gaps and complete service interruptions. Second when a UAVs abandons a user during service delivery due to a malfunction or unexpected abandonment, it can lead to a sudden interruption and directly impact the user experience, especially in critical applications such as emergencies or real-time streaming. The effectiveness of this approach lies in its ability to maintain stable QoS by minimizing downtime and response times, ensuring continuous coverage without the need for radical changes to the network architecture or additional costs. These systems rely on flexible and dynamic resource management mechanisms, allowing for intelligent load redistribution across available UAVs based on real-time network conditions, enhancing performance efficiency and reducing the probability of service failure.

3.3 Overview and description of the system model

The system is designed to ensure service continuity and provide reliable coverage in environments that rely on UAVs, particularly during emergencies or unstable conditions where crowd-sourced UAVs may face challenges such as low battery levels, bandwidth congestion, unavailability or sudden abandonment. The system integrates the BS with crowd-sourced UAVs and backup UAVs to deliver continuous and efficient coverage, especially in high-density user areas lacking robust fixed infrastructure. Crowd-sourced UAVs are the primary element in serving users based on specific coverage and efficiency criteria, but they may encounter limitations in certain situations. This is where backup UAVs play a critical role, as they are activated automatically to maintain service continuity. The system selects backup UAVs based on their battery levels and bandwidth compatibility to ensure seamless coverage without affecting performance. The cost of backup UAVs is determined in proportion to the conditions affecting crowd-sourced UAVs, ensuring that users are not burdened with additional unexpected costs during emergencies. The UAVs are deployed at altitudes ranging from 50 to 150 meters to reduce mobility and enhance communication stability, with backup UAVs activated as needed to distribute the load flexibly and minimize the impact on service quality.
Figure 3.1 illustrates the system design, showing the base station at the center, surrounded by crowd-sourced UAVs, backup UAVs, and users. For more details on the operation of crowd-sourced UAVs, please refer to source [19].

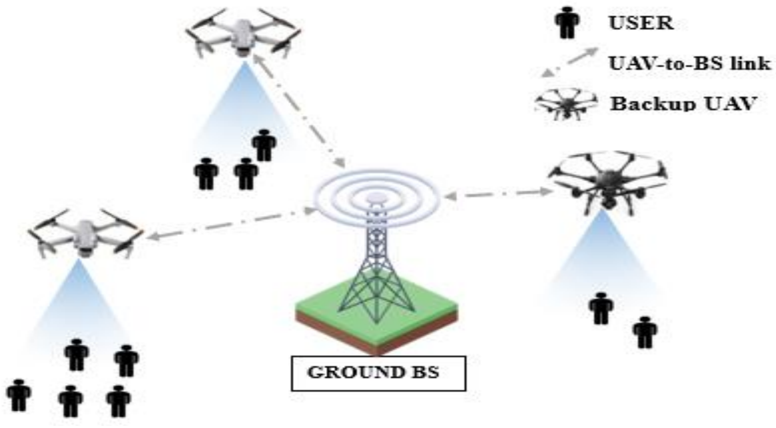


Figure 3.1:Overview of the Proposed System

3.3.1 System components

BSs play an important role in supporting the dynamic network of UAVs with enhanced features. They have NR capabilities with support for both FR1 (low to medium frequencies) and FR2 (high frequencies - millimeter bands), providing wide coverage that enables UAV and users (UEs) to communicate even over long distances or high density areas. They also have advanced computing capabilities for real time data processing, such as managing handovers between UAV, dynamically updating standby UAV_{system} and working UAV_{worker} lists and making UAV replacement decisions based on battery, service and cost criteria. The BS is also the primary reference point for the system, as it is not only the only communication bridge with the infrastructure, but also the element responsible for coordinating operations between UAV such as connecting replacement UAVs UAV_{sk} or UAV_{sw} to users when emergencies occur (battery low, congestion, absence or abandoned of the crowd-sourced UAV), while evaluating the effectiveness of the system by comparing performance with the model. Traditionally, BS makes the key driver for improving network stability and reducing downtime by enabling UAVs to operate as flexible, interchangeable units based on operating conditions.

UAVs

- **Crowd-sourced UAVs** are UAVs that can join the system at any time and are added to a waiting list known as *UAVlist = {UAV1, UAV2, ..., UAVj}.* For more details on crowd-sourced UAVs see [19]. They operate synchronously with the system's backup UAVs to ensure greater stability and reliability of the system.

- **Backup UAVs** The improved system contains a list of backup UAVs known as $UAV_{system} = \{UAVs1, UAVs2,..., UAVsk\}$. These backup UAVs $\mathrm{UAV}_{\mathrm{sk}}$ are arranged according to bandwidth in ascending order, so that they can be used in the system in emergency situations, including low battery of the UAV full bandwidth of the UAVs or in the event of its unavailability or abandonment by users during their service. The BS starts in one of the emergency situations mentioned above each according to the situation, as shown in Function 3, by searching for the appropriate backup UAVs. Each time, the selection is made from the $\mathrm{UAV}_{\mathrm{system}}$ list provided that the backup UAV meets the minimum required bandwidth and that the battery is ≥ 70%. The price is also determined according to the situation, either fixed by the system or identical to the UAVs that the selected backup UAVs will replace to serve users, as shown in Function 3 bestUavbackup(). After selecting the appropriate backup UAVs, the users are transferred via Handover operation, then the selected backup UAVs is removed from the $\mathrm{UAV}_{\mathrm{system}}$ and added to the $\mathrm{UAV}_{\mathrm{worker}}$ list defined as $UAV_{worker} = \{UAVs1, UAVs2,..., UAVsw\}$, and finally when each backup working UAV $\mathrm{UAV}_{\mathrm{sw}}$ finishes its work it is removed from the $\mathrm{UAV}_{\mathrm{worker}}$ list and added to the $\mathrm{UAV}_{\mathrm{system}}$ list as shown in Function 1, when it returns to the $\mathrm{UAV}_{\mathrm{system}}$ list it is recharged and maintained to become ready to work when needed.
- **Users (UEs)**

Users represent the core component of the proposed system, providing network connectivity services. Users can log in at any random time and are added to a list $UElist = \{UE1, UE2, ..., UEi\}$. For more details see [19]. After selecting the appropriate UAV for the user's requirements and completing the payment, the user is assigned a UAV. If the system does not have a backup UAV, a backup UAV is called. If backup UAVs are also unavailable, service is provided directly from the BS if a UAVHSA system is used, ensuring service continuity.

- **The BS**

The BS is important as it hosts the system, and manages all the components. The BS provides the connectivity to users and UAVs. The BS is also responsible for controlling backup UAVs and it keeps information on the connection of users and their UAVs and it also handles payment and more.

3.3.2 System assumptions

This research aims to improve the physical layer and achieve user satisfaction by providing high network connectivity, focusing on evaluating the efficiency of the RAN as a key component of system effectiveness. This work involves integrating UAVs with BS and backup UAVs. The backup UAVs are an important part of the system as they further improve the system's resistance to emergencies and provide greater stability. The system relies on 5G technologies to provide resources close to users and can be deployed independently at all station locations, with each user and crowd-sourced or backup UAV connected to a single BS. Network segmentation is based on services such as eMBB, from which users can select appropriate services, giving network providers greater control over resource management. We assume that no interference between UAVs occurs and that UAV to BS connectivity is optimal.

3.3.3 System details and methodology overview

A. System coordination and algorithms UAVs and Users UE_i are considered independent entities, while the system coordinates the communication and payment process between these entities. When a new UAV registers, it is ranked according to its price if it is publicly owned. If the UAV is classified as a backup, it is added to the backup UAV list UAV_{system} based on its bandwidth. With each user connection, the system searches the UAV list to find the first suitable UAV. If a suitable UAV is not found or is unavailable, a suitable backup UAV is selected, removed from the UAV system list and added to the UAV_{worker} list. UAV statuses and prices may change frequently and the system regularly updates this information in its database. Furthermore, the system assigns UAV to users and tracks all UAV_j - UE_i or UAV_{sw} - UE_i pairs. The system is also solely responsible for all financial transactions between the two parties, for economic reasons and to maintain trust.

B. Finance, Payment and Pricing Profit generation is one of the primary objectives of the system, which aims to ensure user satisfaction and profitability for crowd-sourced UAV owners. To achieve this, the system acts as an intermediary to manage financial transactions between the parties involved. A prepayment system for the user and a post payment system for the UAVs has been implemented to ensure that UAVs remain operational [19]. In several other emergency situations, there is a need to call for backup UAVs, whose pricing is either fixed by the system or identical to the UAV that will be replaced, where this pricing is based on the need.

c. Proposed Algorithms and functions

Explication of function 1:

The main goal of Function 1 is to monitor the status of the working standby UAV UAV$_{\text{sw}}$ so that as long as this UAV is serving users, it remains in the UAV$_{\text{worker}}$ list. However, if its service is finished, no user remains connected to it, it is deleted from the UAV$_{\text{worker}}$ list and added to the UAV$_{\text{system}}$ list to be available when needed again.

Function 1: Function removeUAVworker()

```
for each $UAV_{sw}$ in UAVworker do
    if $UAV_{sw}$ is still connected to users then
        /* Keep in UAVworker*/
        $UAV_{sw}$ is still operating
    Else
        /* $UAV_{sw}$ finished its task*/
        REMOVE $UAV_{sw}$ from UAVworker
        ADD $UAV_{sw}$ to UAVsystem AND RETURN UAV to station
    end if
end for
```

Explication of function 2:

The main goal of Function 2 is to illustrate the management mechanism of the UAV$_{\text{backup}}$ drone while in standby mode. If the battery level is below the threshold (70%), the UAV is activated for a short period to recharge or to keep essential systems running, then returned to standby mode with reduced power consumption by shutting down non-essential systems.

Function 2: Function UAVs-in-standby-mode ()

```
if UAVbackup is in standby mode then
    if UAVbackup battery level is below a certain threshold then
        /* Activate UAVbackup for short period to maintain battery level */
        Activate UAVbackup for short time to recharge or keep systems running
    Else
        /* Keep UAVbackup in standby with minimal power usage */
        Put UAVbackup back in standby mode (reduce non-essential systems like GPS)
    end if
end if
```

Explication of function 3:

The main goal of Function 3 is to implement an emergency management algorithm to ensure service continuity in the UAV network when problems occur. This function addresses four main scenarios for managing UAV replacements in the communication network. The process begins by checking the battery level of the crowd-sourced UAV UAV_j is low. A backup UAV UAV_{sk} is selected from the UAV_{system} list, which must meet two conditions supporting the same or more services as UAV_j and its battery level must be ≥ 70%. The replacement UAV is assigned the same cost as UAV_j, receives the connected users via handover. Also, if bandwidth congestion occurs on UAV_j, the system first searches for a working backup UAV UAV_{sw} in the UAV_{worker} list. If none is found, the system searches again in the UAV system list. If a suitable UAV is found, it is transferred from the UAV_{system} list to the UAV_{worker}. Also, if the crowd-sourced UAV is not present, the list of working backup UAVs is searched. If a suitable one is found, it is connected to the user. If not, a suitable backup UAV is selected from the UAV_{system} list with a battery level ≥ 70% and an appropriate bandwidth. The system sets a fixed cost for the UAV_{sk}. A while loop then starts and continues until the user UE_i connects to the selected backup UAV. During each iteration, the system checks the list of existing UAVs in the system. If a new UAV_j appears that supports the same services, it replaces the working backup UAV. Finally, if UAV_j abandons user, a backup UAV with the same service conditions is selected. The while loop then searches for UAV_j in the original list. If none are found, the system searches for a suitable UAV in the UAV_{worker} list. If found, it replaces the UAV_{sk}. If not, the UAV_{sk} is connected to the user and then transferred to the UAV_{worker}. When a backup working UAV_{sw} 's mission ends, it is removed from the UAV_{worker} and added back to the UAVsystem() using the removeUAVworker() function.

Function 3: Function bestUavbackup()

```
/* Check if $UAV_j$ needs assistance from backup UAV */
if UAVj battery level is low then
    /* Select the best backup $UAV_{sk}$ from $UAV_{system}$ */
    Select best $UAV_{backup}$ from $UAV_{system}$ where $UAV_{backup's\ services}$ >= Crowd-sourced UAV's services AND battery level of $UAV_{sk}$ >=70%
    Set Price $UAV_{sk}$ =Price UAVj
    /*UAVsk keep flying ,not yet connected to the user*/
    $UAV_{sk}$ connects to BS and receives UEi from UAVj
    if $UAV_{sk}$ connect to UEi then
        REMOVE $UAV_{sk}$ from $UAV_{system}$
        ADD $UAV_{sk}$ to $UAV_{worker}$
    end if
    /* when the $UAV_{SW}$ finishes its work*/
    Call Function removeUAVworker()
else if band congestion occurs then /* where the band of UAVj is full */
    if $UAV_{SW}$ is available in UAVworker then
        Search for alternative $UAV_{SW}$ from UAVworker and connect UEi
    Else
        Search for alternative $UAV_{sk}$ from UAVsystem and connect UEi
        if $UAV_{sk}$ connect to UEi then
            REMOVE $UAV_{sk}$ from UAVsystem
            ADD $UAV_{sk}$ to UAVworker
        end if
    end if
    /* when the $UAV_{SW}$ finishes its work*/
    Call Function removeUAVworker()
else if UAVj is not available then /* there is no UAVj in the UAVlist */
    if $UAV_{SW}$ is available in UAVworker then
        Connect UEi to $UAV_{SW}$
    Else
        Search for alternative $UAV_{sk}$ from UAVsystem where battery $UAV_{sk}$ >=70%
    end if
    price of $UAV_{sk}$ is fixed by the System
```

```
    while UEi is still not connected to UAVbackup do
        the systeme verifies the list of UAVj
        if a new UAVj is found in the list with the same services of UEi then
            System replace UAVbackup with UAVj to serve the connected user
        end if
    end while
    if $UAV_{sk}$ connect to UEi then
        REMOVE $UAV_{sk}$ from UAVsystem
        ADD $UAV_{sk}$ to UAVworker
    end if
    /* when the $UAV_{SW}$ finishes its work*/
    Call Function removeUAVworker()
else if UAVj abandoned then
    Select the best $UAV_{sk}$ from UAVSystem where battery $UAV_{sk}$ >=70%
    Set Price $UAV_{sk}$ =Price UAVj
    while UEi is still not connected to $UAV_{sk}$ do
        Search for alternative UAVj from UAVlist
        if found UAVj from UAVlist then
            System replace $UAV_{sk}$ with UAVj to serve the connected user
        else Search for alternative $UAV_{sw}$ from UAVworker
            if found $UAV_{sw}$ from UAVworker then
                System replace $UAV_{sk}$ with $UAV_{sw}$ to serve the connected user
            end if
        end if
    end while
    if $UAV_{sk}$ connect to UEi then
        REMOVE $UAV_{sk}$ from UAVsystem
        ADD $UAV_{sk}$ to UAVworker
    end if
    /* when the $UAV_{SW}$ finishes its work*/
    Call Function removeUAVworker()
end if
```

Explication of algorithm 1:

The main goal of Algorithm 1 to prioritize the system's backup UAVs based on their resources. The algorithm begins by fetching all backup UAVs from the system, then sorts them in ascending order based on their available bandwidth. Finally, the system is updated with the prioritized list of backup UAVs, making them ready for future missions.

Algorithm 1: sortUAVsystemByPriority

```
/* Retrieve all UAVs from the system */
UAVretrieve = getAllUAVs(UAVsystem)
/* Sort the UAVs: -by bandwidth ascending*/
SortedUAVretrieve = sort(UAVSystem by (bandwidth ascending))
/* Update the system with the sorted UAVretrieve */
updateUAVsystem(UAVsystem, SortedUAVretrieve)
```

Explication of algorithm 2:

The main goal of Algorithm2 represents the lifecycle of the crowd-sourced UAV UAV_j, starting from its attempt to connect to the nearest BS until it finishes its work or leaves the system. If UAV_j is registered as a worker it connects to the BS and begins performing its tasks. During its operation, the crowd-sourced UAV exchanges information with the BS, including location data, status, battery level and the service price. The system updates various lists based on this information such as UAV_{list} (for managing all crowd-sourced UAVs) UAV_{system} (for backup UAVs) and UAV_{worker} (for active UAVs).When a new user UE_i is assigned to the crowd-sourced UAV, it starts providing the required service. After completing the service, the crowd-sourced UAV receives payment from the user. If the crowd-sourced UAV requires assistance the bestUavbackup() function is invoked to provide a backup UAV. If the crowd-sourced UAV decides to finish its operation and has no connected users, it is marked as finished. However, if the crowd-sourced UAV suddenly abandons its tasks, the bestUavbackup() Function3 is also called to ensure continuity of service. Finally, the backup UAV in standby mode are monitored to check their battery levels. A low-power mode is activated when needed to maintain their efficiency while they await deployment.

Algorithm 2: UAV life-cycle

```
UAVj attempts to connect to the nearest BS for the first time;
if UAVj is registered as a worker then       /* Check UAV registration */
    UAVj connects to BS;
    while UAVj is not finished working and UAVj has not abandoned do
        BS sends current prices to UAVj;
        UAVj updates and sends its info to BS;
        /*UAV info consists of location data, required price, and other status and battery info*/
        system updates UAVlist and sorts with updated info (based on price);
        system updates UAVsystem and sorts with updated info (based on bandwidth);
        system updates UAVworker and sorts with updated info (based on price);
        if UAVj is assigned a new UEi then
            Start serving new user UEi;
        end if
        UAVj is serving its connected users;
        /* UAVj receives payment for the finished user*/
        /*Check if UAVj needs assistance from backup UAV */
        bestUavbackup() ;  /* Call Function */
    end while
    /*does UAVj want to leave?*/
    if UAVj has no connected users and UAVj wants to finish then
        Set UAVj -Finished to True;
    Else
        Wait for connected users to finish;
    end if
    if UAVj abandoned then
        bestUavbackup() ;     /* Call Function */
    end if
end if
/* Monitor backup UAVs in standby mode  "Check battery levels of UAVs in standby"*/
for each UAVbackup in UAVsystem do
    UAVs-in-standby-mode () ;  /* Call Function */
end for
```

Explication of algorithm 3:

The main goal of Algorithm3 outlines the user's lifecycle, which begins with the user attempting to connect to the nearest BS. If the BS is accessible, the lifecycle progresses as the system initiates a search for a suitable UAV within the UAV_{list} to serve the user. When finding an appropriate UAV UAV_j, the user completes the payment process and UAV_j starts providing the required service. If no suitable UAV is available, the system transitions to using backup UAVs through the bestUAVBackup() function described in Function3. If backup UAVs are also unavailable, the user's cycle concludes. At this point, if the system supports it, the hybrid mode is activated to ensure the user remains connected to the BS.

Algorithm 3: User life-cycle

```
UEi attempts to connect to the nearest BS;
if BS is available then
    Search for the best UAVj in UAVlist
    /*verification list of UAVlist available or not in real time*/
    if UAVj is available then
        UEi pays the required amount to the system;
        System assigns UAVj to UEi;
        UAVj starts serving UEi;
        while UEi is connected and has not abandoned do
            if UEi finishes its session then      /* Monitor UEi session */
                Wire payment to UAVj;
                Disconnect UEi;
            end if
        end while
    else  / UAVj is not available*/
        bestUavbackup () ; /* Call Function */
        if no backupUAV is found then   /* No available UAVs  */
            if hybrid mode is enabled then
                Connect UEi to BS;
            Else
                Mark UEi as not connected;
            end if
        end if
    end if
Else
    Mark UEi as out of range and unable to connect;
end if
```

a. Proposed UML activity diagrams

Explication of figure 3.2 :

This diagram in Figure 3.2 illustrates the management mechanism of the UAV backup while in standby mode. If the battery level is below the threshold (70%), the UAV is activated for a short period to recharge or to keep essential systems running, then returned to standby mode with reduced power consumption by shutting down non-essential systems. However, if the battery level is equal to or above 70%, the UAV remains in standby mode directly, with the same power-saving measures applied.

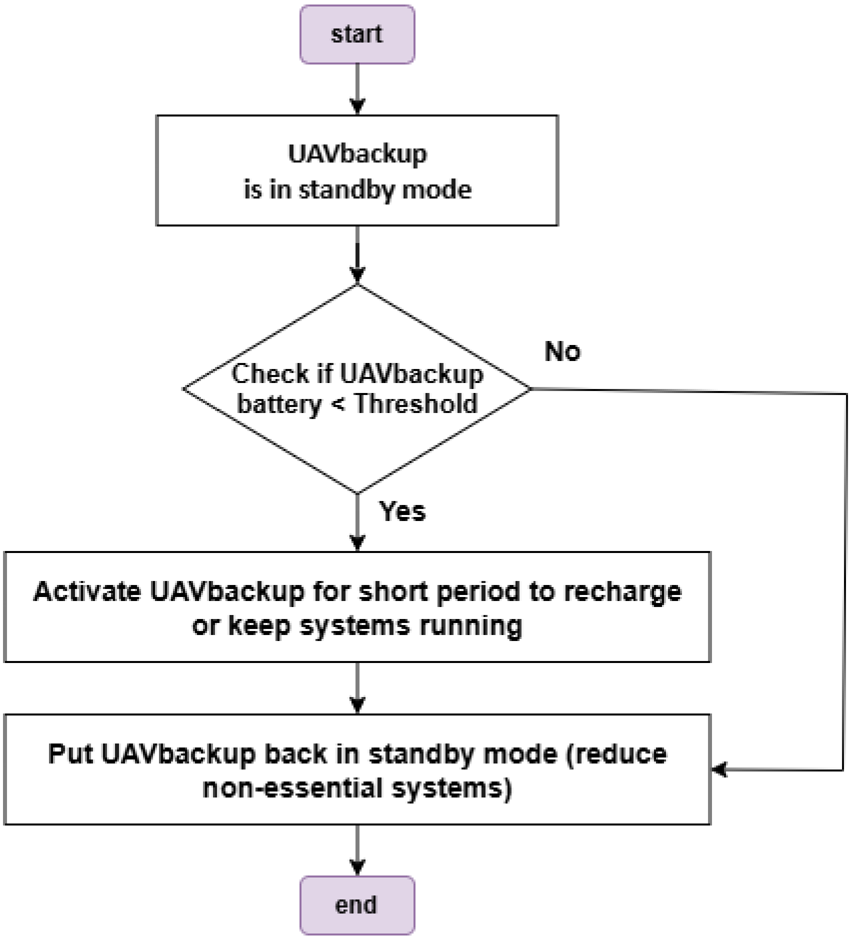


Figure 3.2: Activity diagram of recharge UAVsystem

Explication of figure 3.3 :

This diagram in Figure 3.3 represents the process of replacing a crowd-sourced UAV UAV_j when its battery level is low while providing a service to the user. The optimal replacement backup UAV UAV_{sk} is selected from the system based on two main criteria that it provides services equal to or better than those provided by crowd-sourced UAVs, and that its battery level is at least 70%. After the backup UAV completes its mission, it is returned to the system for future use.

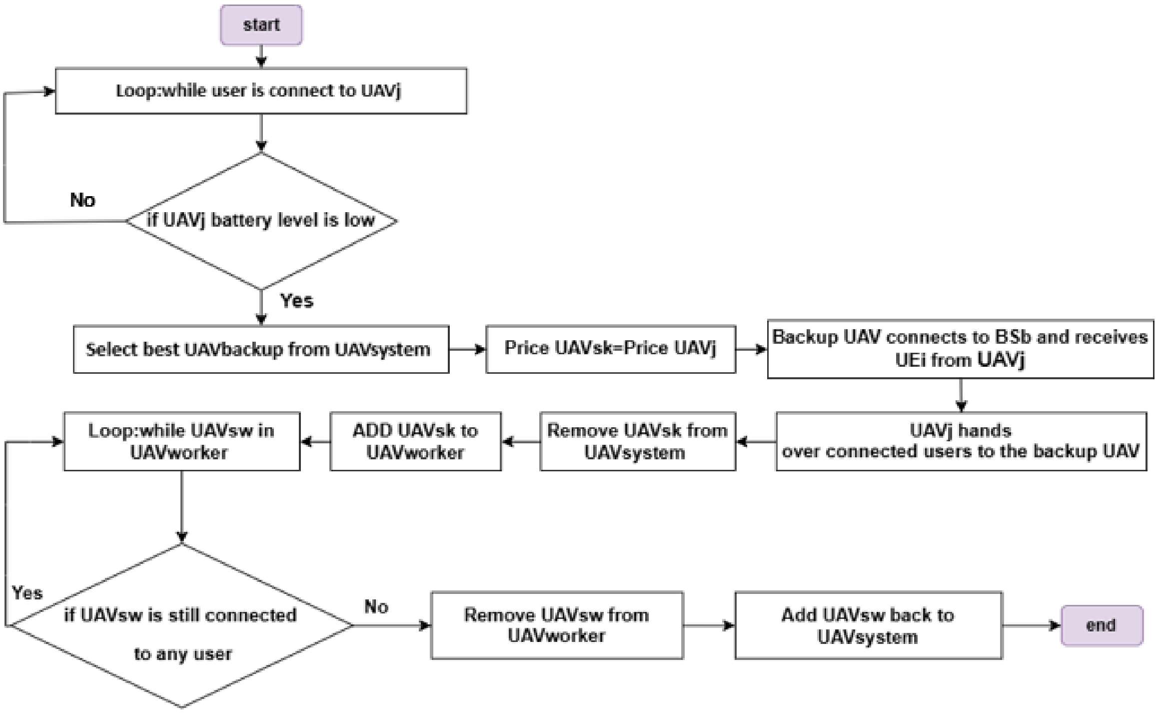


Figure 3.3: Activity diagram of UAVj battery level is low

Explication of figure 3.4:

The diagram in Figure 3.4 describes the user's lifecycle, which starts with the user's attempt to connect to the nearest BS. If the BS is available, the user's lifecycle begins as the system searches for a suitable UAV for the user. The search starts in the UAV_{list}. If a crowd-sourced UAV UAV_j is available, the user proceeds to pay the system and UAV_j begins serving the user. If UAV_j is not available, the system relies on UAV backup through the function bestUAVBackup(), as described in Function 3. The user's cycle ends if no backup UAV is available. At this point, the hybrid mode is invoked, provided it is supported by the system. The hybrid mode ensures the user is connected to the BS.

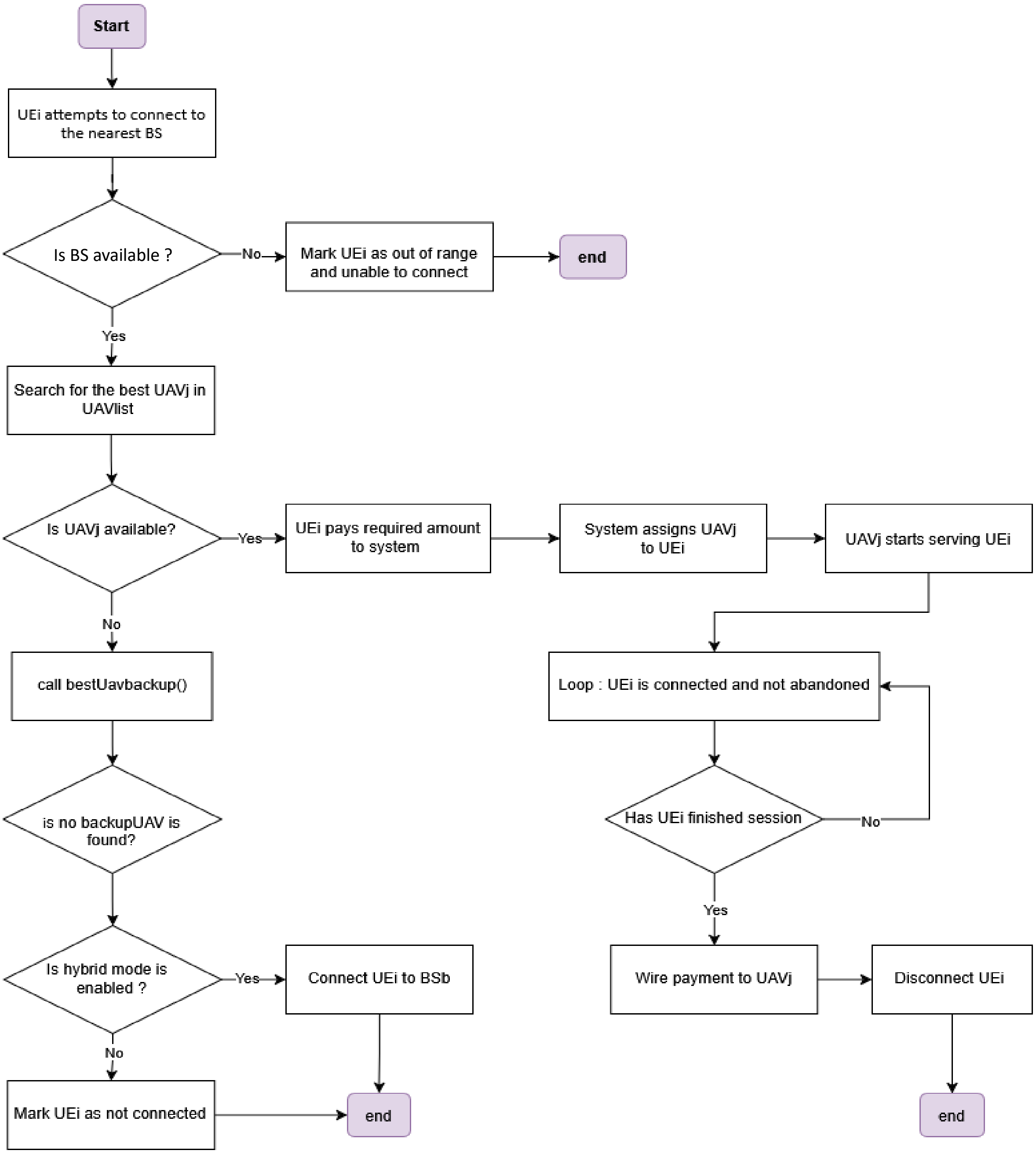


Figure 3.4: Activity diagram of User life-cycle

Explication of figure 3.5:

The diagram in Figure 3.5 describes the availability of UAV$_j$, which begins by checking the availability of any crowd-sourced UAV$_j$ in the UAV list. If UAV$_j$ is available, it immediately begins serving the user. If not, the list of working backup UAVs is searched. If a suitable UAV$_{sw}$ is found, it is connected to the user. If none is found, the system searches for a backup UAV UAV$_{sk}$ from the UAV$_{system}$. Once a UAV$_{sk}$ is selected, the system sets a fixed price for it and the UAV$_{sk}$ is dispatched to serve the user. During the dispatch phase, the system continuously monitors the UAV_{list} for any updates. If a new UAV_j that meets the user's requirements becomes available, it replaces the backup UAV_{sk} and connects to the user. If no new UAV_j is found, the UAV_{sk} completes the task is removed from the UAV_{system} and is added to the UAV_{worker} list to begin serving the user. Additionally, when a UAV_{sw} is finished serving users, it is removed from the UAV_{worker} list and returned to the UAV_{system}.

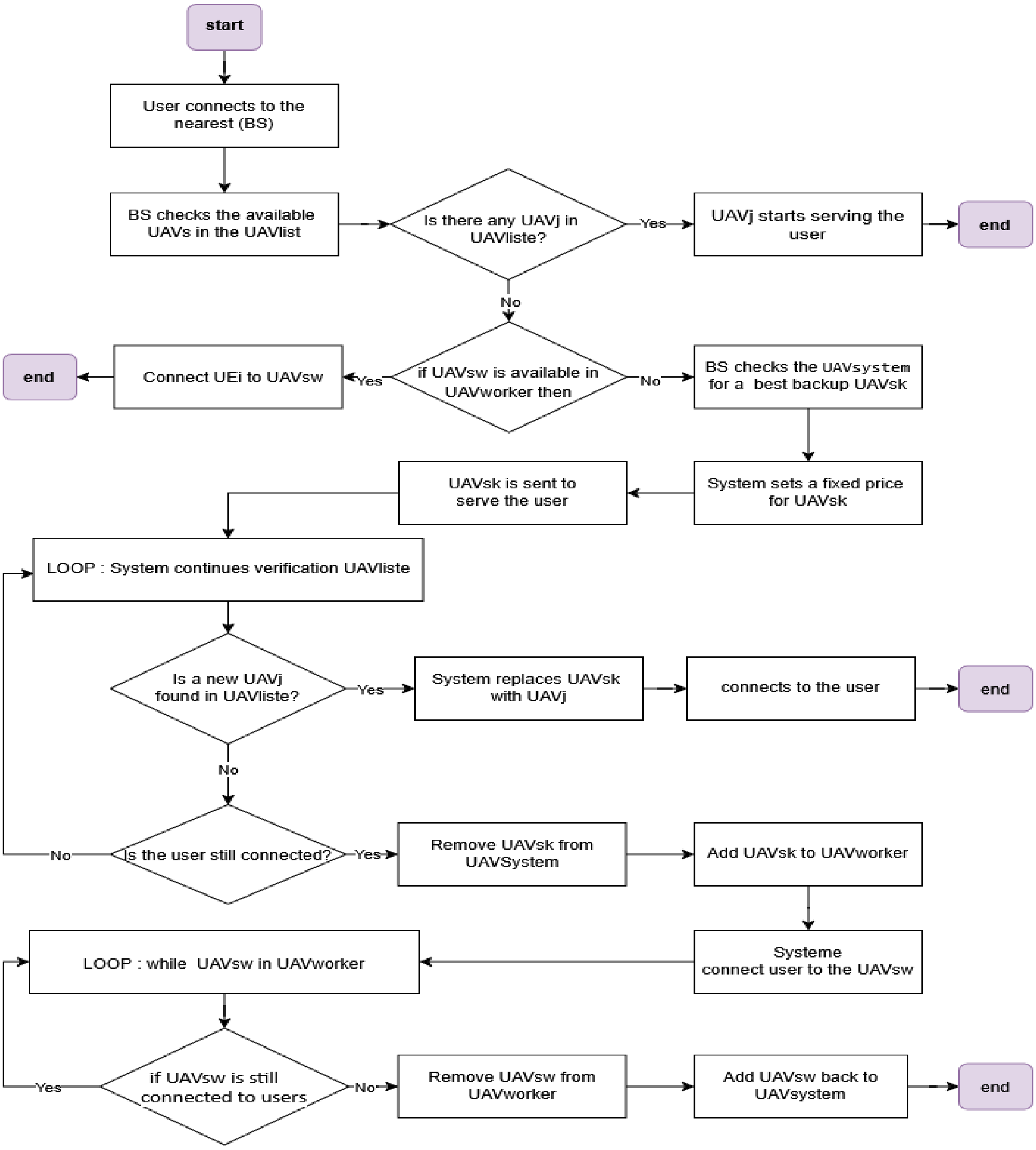


Figure 3.5: Activity diagram of availability of UAVj

3.4 Summary

This chapter presents a model that utilizes UAVs in a network, combining previous technologies with existing improved solutions. It illustrates this by integrating backup UAVs into the system to ensure continuity and QoS under various conditions. This solves problems faced by the previous system such as service interruptions due to UAV low battery, bandwidth congestion and sudden absence and unavailability during the service. These backup UAVs are always ready to help in emergencies with improved algorithms for selecting the best backup UAV based on precise rules. The pricing mechanism has also been improved to ensure system reliability. This represents an improvement in future communication systems, especially in dense environments. In the next chapter, we will demonstrate the implementation of the algorithms and diagrams presented in this chapter.

Chapter

4

Implementation and Simulation Results

4.1 Introduction

In the previous chapter, we discussed the theoretical aspect which includes the algorithms and UML activity diagrams related to the optimizations added to the previous study. This optimization considered an effective system model that integrates the operation of crowd-sourced UAVs with emergency backup UAVs. This chapter explains the practical part of the study which is an essential part of the system and which illustrate the benefits of the optimizations discussed previously. MATLAB was used for the simulation part and Excel was used to convert the obtained simulation results into graphical representations.

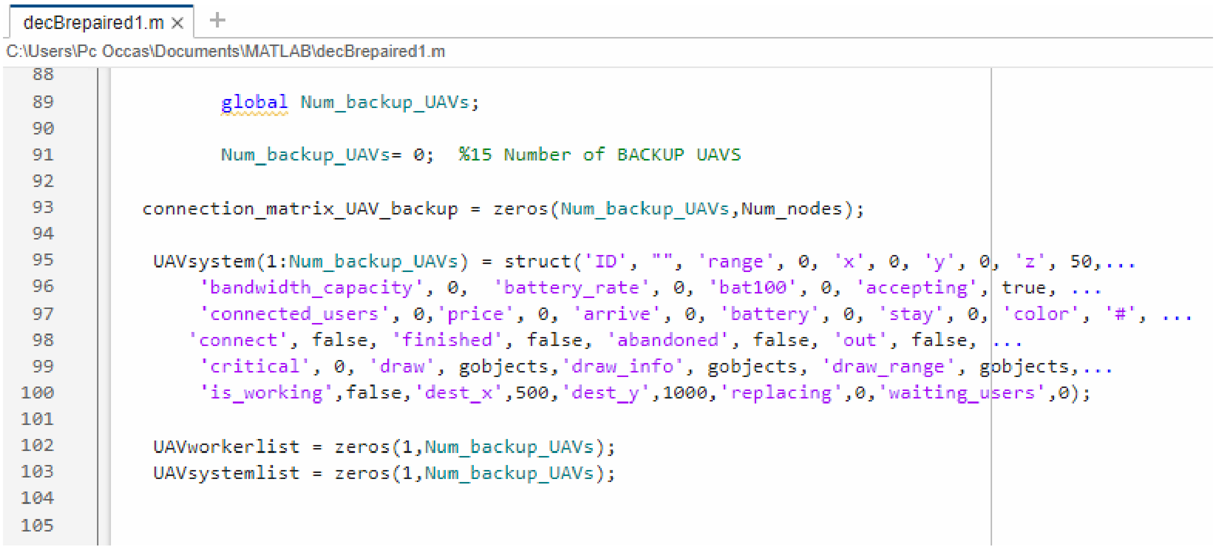
4.2 Matlab and simulation environment

- **Overview of MATLAB**: It is a programming environment and computer program specialized in mathematical, engineering, scientific operations and is widely used in research, simulation and data analysis. Its capabilities in handling matrices, graphs and complex algorithms make it an ideal tool for simulating dynamic systems such as the functions and algorithms presented in the previous chapter. In this work, MATLAB R2024b was used to implement functions such as simulate the movement of a backup UAVs UAV_{system} and analyze network performance in environments with high user density. The simulations were performed on a computer equipped with an Intel i3 processor. The simulation data and results were collected from the MATLAB program.
- **Tools and Simulation:** It contains specialized libraries such as MATLAB Simulink, Statistics and Machine Learning Toolbox, System Identification Toolbox Control System Toolbox, Communications Toolbox for simulating complex systems such as UAVs movement or wireless channel analysis.

4.3 Code implementation

We converted the algorithms to Matlab code by dividing the tasks into independent functions such as task allocation, user and UAV management and status update etc, making the code easier to develop and maintain.

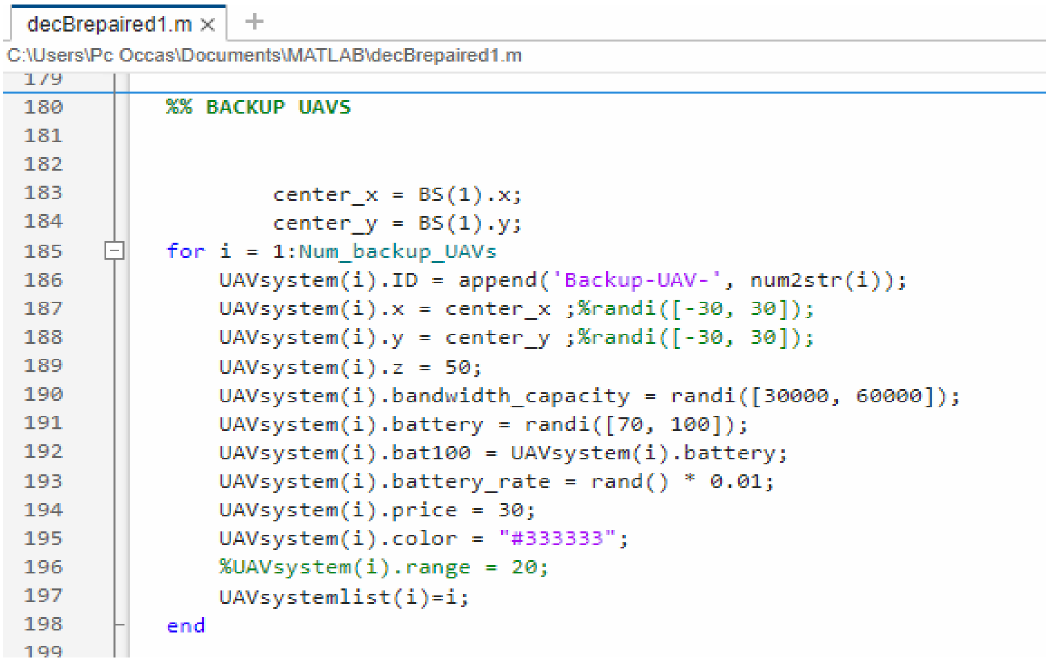
We added variables for backup UAVs such as UAVsystemlist, UAVworkerlist, Num_backup_UAVs and their statuses, to the original code. These variables were defined at the beginning of the code as shown in Figure 4.1, so that the status of each backup UAV could be tracked and updated as needed.



```
        global Num_backup_UAVs;

        Num_backup_UAVs= 0;  %15 Number of BACKUP UAVS

  connection_matrix_UAV_backup = zeros(Num_backup_UAVs,Num_nodes);

   UAVsystem(1:Num_backup_UAVs) = struct('ID', "", 'range', 0, 'x', 0, 'y', 0, 'z', 50,...
       'bandwidth_capacity', 0,  'battery_rate', 0, 'bat100', 0, 'accepting', true, ...
       'connected_users', 0,'price', 0, 'arrive', 0, 'battery', 0, 'stay', 0, 'color', '#', ...
      'connect', false, 'finished', false, 'abandoned', false, 'out', false, ...
       'critical', 0, 'draw', gobjects,'draw_info', gobjects, 'draw_range', gobjects,...
       'is_working',false,'dest_x',500,'dest_y',1000,'replacing',0,'waiting_users',0);

   UAVworkerlist = zeros(1,Num_backup_UAVs);
   UAVsystemlist = zeros(1,Num_backup_UAVs);
```

Figure 4.1:Initializing the Backup UAVs Data Structure and Variables

Figure 4.2 also represents a section for generating a set of backup UAVs and storing their information in a data structure called $\text{UAV}_{\text{system}}$.



```
%% BACKUP UAVS


        center_x = BS(1).x;
        center_y = BS(1).y;
for i = 1:Num_backup_UAVs
    UAVsystem(i).ID = append('Backup-UAV-', num2str(i));
    UAVsystem(i).x = center_x ;%randi([-30, 30]);
    UAVsystem(i).y = center_y ;%randi([-30, 30]);
    UAVsystem(i).z = 50;
    UAVsystem(i).bandwidth_capacity = randi([30000, 60000]);
    UAVsystem(i).battery = randi([70, 100]);
    UAVsystem(i).bat100 = UAVsystem(i).battery;
    UAVsystem(i).battery_rate = rand() * 0.01;
    UAVsystem(i).price = 30;
    UAVsystem(i).color = "#333333";
    %UAVsystem(i).range = 20;
    UAVsystemlist(i)=i;
end
```

Figure 4.2:Creating and Distributing Backup UAVs Around the Base Station (BS)

The code generally works by simulating various UAV scenarios. Tasks are distributed to the crowd-sourced UAVs. In the event of a failure, the backup UAVs are automatically activated via dedicated functions, like Launch_system_UAV, this is responsible for launching a backup UAV and directing it to the location of the user in need of support. the second function is closest_backup_UAV this searches for the closest available backup UAV (worker or standby), to serve the user who cannot find a crowd-sourced UAV. Third function is fly_UAV_to_destination, this function moves the backup UAV to the desired location usually the user's location or the failed crowd-sourced UAV. The fourth function is serve_backup, this function connects the user to the backup UAV and updates the connection status and capacity. The fifth function is UAV_backup_update_status, this function updates the status of the backup UAVs (battery, capacity... etc). The sixth function is convert_worker_list, function for managing backup UAV lists (moving an UAV from the system list to the working list and the other way around). Also the draw_backupUAV function for plotting and updating the position and status of the backup UAV on a graph.

During the simulation, the code collects important data such as number of crowd-sourced UAVs, number of backup UAVs, number of users connected and disconnected and time of simulation…etc. This data is stored in arrays or tables and then exported to an Excel file shown in Figure 4.3, for easier graphing and analysis.

```
        % EXCEL RESULTS

FINAL_excel_all = [];
all_user_connections = all_user_connections+connections_to_crowd + connections_to_backup;

PARAMS_and_RESULTS = struct('Users',Num_nodes,'UAVs',Num_uavs,'backup_UAVs',Num_backup_UAVs,...
    'Time',simulation_time,'Mode',Hybrid_sys,'FR',FR, 'replaced_critical_battery',0,...
    'connections_to_crowd',connections_to_crowd,'connections_to_backup',connections_to_backup,...
    'all_user_connections',all_user_connections,'handovers',handovers,'backup_handovers',backup_handovers,...
    'finished',user_states(1),'abandoned',user_states(2),'out',user_states(3));

FINAL_excel = struct2table(PARAMS_and_RESULTS);
FINAL_excel_all = [FINAL_excel_all; FINAL_excel];
disp(PARAMS_and_RESULTS);
writetable(FINAL_excel_all, 'results.xlsx', 'Sheet', 3,'WriteMode', 'append');%'WriteMode', 'append'


        end  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Figure 4.3: MATLAB code to create an Excel file from data

4.4 Graphs and results

In this part, we present the practical side of the improvements was mentioned in the previous study, namely backup UAVs. We proposed several four scenarios that clarified the role of these backup UAVs in emergency situations and the improvements they provided to the previous system in terms of user satisfaction and system quality. Below is an explanation and analysis of these scenarios, accompanied by graphs that illustrate their results and in all of these scenarios we use the FR2 because it focuses on achieving very high data transfer speeds with limited coverage, which prefers a direct LoS between the UAV, the user and the BS to ensure low interference. It is typically used in crowded areas such as stadiums, malls and airports which is the target of UAVs in this work.

4.4.1 Scenario one

In this scenario, we will compare the backup system to the regular system in terms of the percentage of abandoned users. For example, the number of users abandoned by crowd-sourced UAVs in the previous system and in the case of backup UAVs and also the number of users handed over from crowd-sourced UAVs to backup UAVs in an emergency.

Table1, titled "Number of Backup UAVs & Crowd-sourced UAVs", shows the number of backup UAVs increasing until it reaches 15 in the system, compared to a fixed number of crowd-sourced UAVs, to prove the importance of backup UAVs in this system, we observe that as the number of backup UAVs is increasing, the system becomes more flexible in terms of user connectivity. Figure 4.4 and Figure 4.5 shows the result of this scenario's objective.

Table 1:Inputs variables for graph results number of abandoned users with and without backup

Constant		Abandoned without backup	Abandoned with backup
Users	UAV crowd-sourced	UAV backup	
460	10	0	3
920	10	0	6
1380	10	0	9
1840	10	0	12
2300	10	0	15

Figure 4.4 titled "Number of abandoned users with and without backup" illustrates the number of users abandoned by the crowd-sourced UAVs with and without using the backup UAVs. In the case where no backup UAVs are available, the system operates with a fixed number of crowd-sourced UAVs 10, as shown in Table 1.We increased the number of users attempting to connect to the system up to 2,300. Simulation results showed that as the number of users increased, the number of abandoned users also rose and reaching a maximum of approximately 500 abandoned users.

However, when backup UAVs were added to the system, increasing their number to 15, the simulation results showed a significant reduction in abandoned users, eventually dropping to nearly zero. This highlights the critical role of backup UAVs in improving the system's performance. Figure 4.5 further explains the reason behind this improvement.

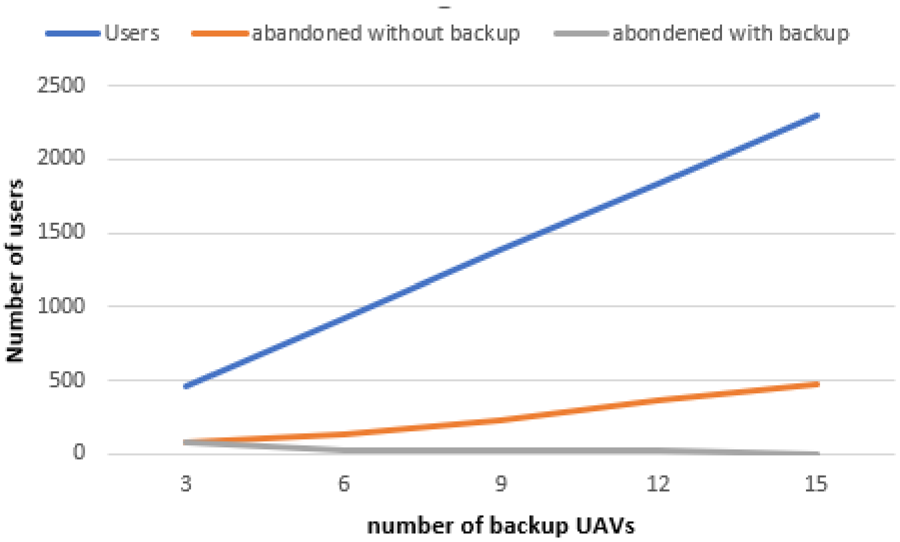


Figure 4.4:Number of abandoned users with and without backup

Figure 4.5 titled “Number of handover users to backup UAVs” illustrates number of users hands over from crowd-sourced UAVs to backup UAVs. In this case We increased the number of users attempting to connect to the system up to 2,300. the simulation results showed a rise in the number of handover processes to backup UAVs, reaching a maximum of approximately 400 handover users.

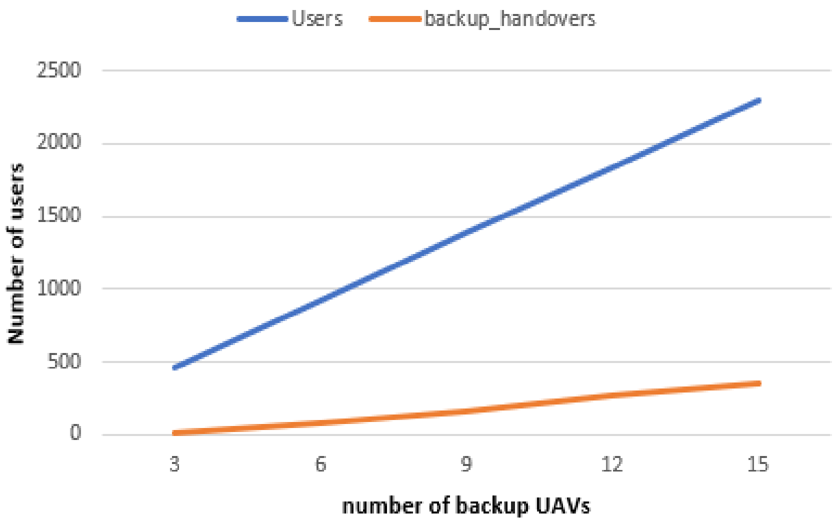


Figure 4.5:Number of handover users to backup UAVs

4.4.2 Scenario two

Figure 4.6 shows the “Number of backup UAVs & crowdsourced UAVs” which represents an increase in the number of backup UAVs versus an increase in the number of crowdsourced UAVs, where for every 10 crowd-sourced UAVs, there are 3 backup UAVs. This is to highlight the role of backup UAVs in the system as shown in Figure 4.7.

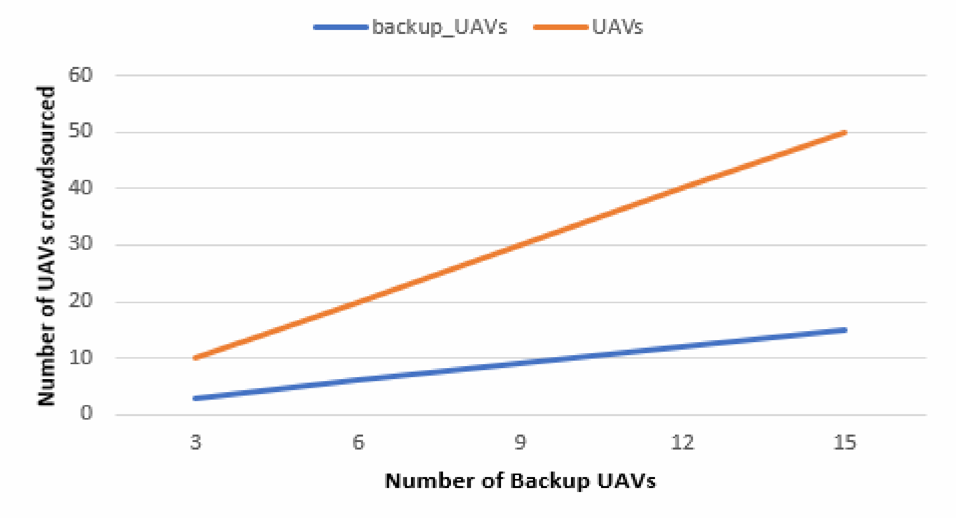


Figure 4.6:Number of backup UAVs & crowdsourced UAVs

Figure 4.7, titled “Effect of Number of Backup UAVs on Connected Users”, illustrates the change in the number of connected users in three status. First, in the UAVSA system and the absence of backup UAVs, we observe the lowest recorded percentage of users in the system. Second, in the presence of backup UAVs we mean UAVSA with backup UAVs, we observed that increasing the number of backup UAVs leads to an increase in the number of connected users. This happens because backup UAVs serve users when needed, especially if crowd-sourced UAVs are unavailable, abandoned or have low battery through a handover process, handing over users to the appropriate backup UAVs. In the third scenario, UAVHSA we observe the highest recorded percentage of users in

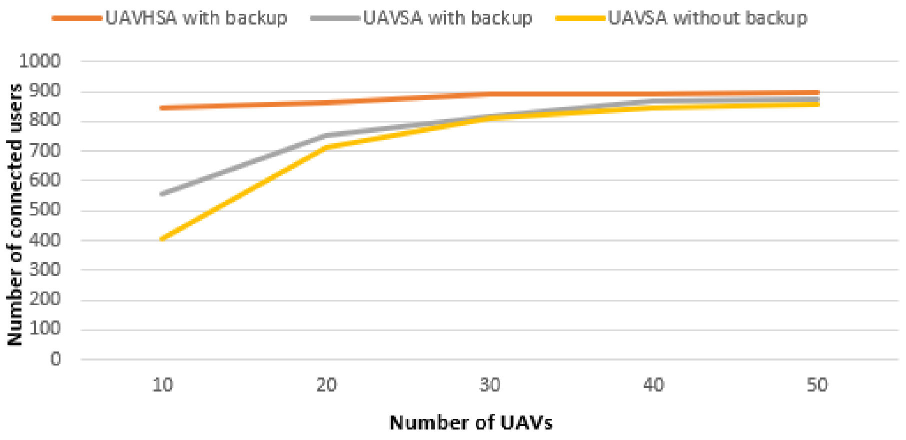


Figure 4.7: Effect of number of backup UAVs on connected users

the system. This occurs when the BS works to serve users if both the crowd-sourced and backup UAVs are not available.

4.4.3 Scenario three

In this scenario, there are no crowd-sourced UAVs available in the system, highlighting the work of backup UAVs, as we see the result in Figure 4.8 below.

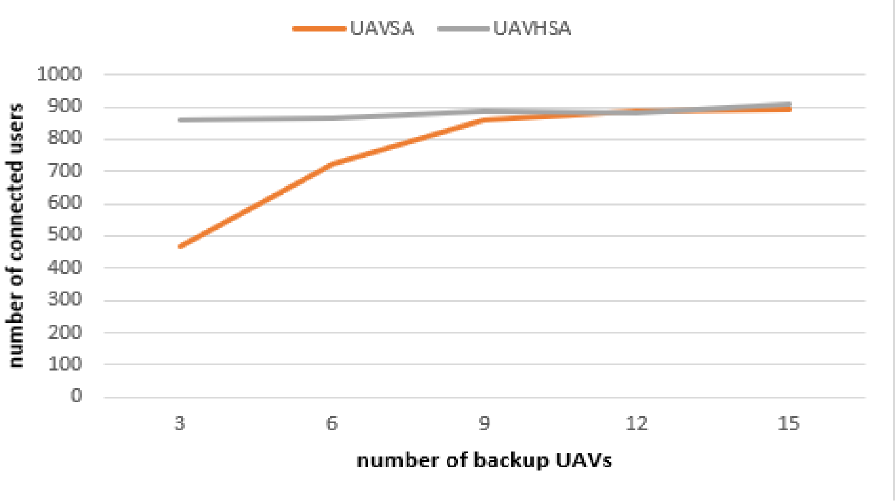


Figure 4.8: Effect of number of backup UAVs on connected users without crowdsourced UAVs

Figure 4.8 shows the “Effect of the number of backup UAVs on the connected users without crowd-sourced UAVs”. We observe that when the hybrid mode is not used and the number of backup UAVs is increased until the system reaches 15 backup UAVs, the number of connected users increases from approximately 500 users for 3 backup UAVs to 900 for 15 backup UAVs connected users and then the number stabilizes. However, when the hybrid mode is used with backup UAVs in the system, we observe stability from the beginning in the number of connected users, approximately 900. This also demonstrates the role of backup UAVs and the improvements they added to the system in increasing the number of connected users.

4.4.4 Scenario four

This scenario represents the increase in the number of users with and without the backup UAVs to illustrate the role and improvements provided by the backup UAVs in increasing the number of connected users in the system.

Table 2, titled “Number of Backup UAVs & Crowdsourced UAVs” shows the number of backup UAVs increasing until it reaches 15 in the system, compared to a fixed number of crowd-sourced UAVs. Figure 4.9 shows the result of this scenario’s objective.

Table 2:Inputs variables for graph result Increasing the number of users with and without backup UAVs

Constant		Users connected without backup	Users connected with backup
Users	UAV crowd-sourced	UAV backup	
460	10	0	3
920	10	0	6
1380	10	0	9
1840	10	0	12
2300	10	0	15

Figure 4.9 shows the increase in the number of connected users with and without backup UAVs. In the case of not using backup UAVs in the previous system, the system operates using only crowd-sourced UAVs fixed at a number of 10, as shown in Table 2. We increased the number of users wishing to connect up to 2300 users.

The simulation results showed that the maximum number of users connected to the crowd-sourced UAVs reached approximately 500 users. In contrast, when adding backup UAVs and increasing their number up to 15 UAVs, the simulation results showed that the maximum number of connected users reached approximately 900 users. This highlights the need for backup UAVs in emergency situations, which plays an important role in improving the system, making it more stable and flexible for users

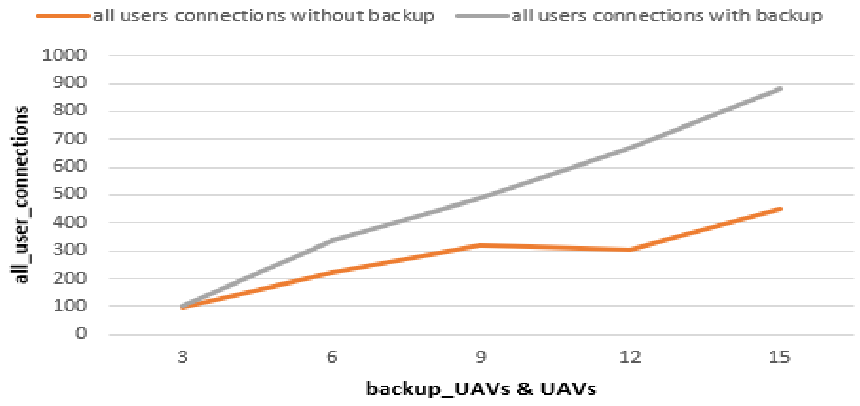


Figure 4.9: Increasing the number of users with and without backup UAVs

4.5 General discussion and comparison

This study highlights the important role of backup UAVs in improving the performance of crowd-sourced UAV systems, focusing on four scenarios that demonstrate the benefits of this technological addition. In the first scenario, the focus was on comparing the traditional system with the system supported by backup UAVs in terms of the percentage of abandoned users. The backup UAVs demonstrated their ability to significantly reduce the number of abandoned users and the graphs also showed an increase in the number of user transfers from crowd-sourced UAVs to backup UAVs in emergency situations, improving communication stability and flexibility. In the second scenario, it was shown that increasing the number of backup UAVs results in a higher number of connected users, especially in hybrid systems that include BS, reflecting strong integration between the various system components. The third scenario illustrated that backup UAVs can achieve system stability even in the absence of crowd-sourced UAVs, helping to increase the number of connected users. Finally, in the fourth scenario, the results showed that the traditional system cannot effectively meet user needs. The presence of backup UAV proved to be essential in a handling the increasing number of users attempting to connect to the system, making the system more efficient in emergencies and congestion. These results highlight the importance of backup UAV as an essential component for improving system quality and ensuring user satisfaction.

4.6 Summary

This chapter explains the practical part of the study, which is a fundamental part of the system and demonstrates the benefits of the improvements we discussed earlier. MATLAB was used for the simulation portion and Excel was used to convert the simulation results into graphical representations. We conducted several scenarios that demonstrated the importance of backup UAV in improving system quality and ensuring user satisfaction.

General conclusion and future works

This thesis aims to study and develop an innovative system that integrates UAVs with 5G network technologies and Network Slicing, with the objective of improving system efficiency and ensuring service continuity, especially in emergency situations such as UAV's battery low, bandwidth congestion of crowd-sourced UAVs or abandoned of users.

The study focused on introducing backup UAVs to address absence or failures of crowd-sourced UAVs, along with developing precise selection mechanisms based on criteria such as battery capacity and bandwidth availability.

A practical model was designed to demonstrate how these backup UAVs are integrated into the main system. A set of simulations were conducted using tools such as MATLAB and Excel to illustrate the effectiveness of the proposed solution in enhancing service continuity and reducing the number of abandoned users.

This study contributes to the development of future communication systems by offering solutions aimed at building communication infrastructures capable of meeting increasing user demands.

As a suggestion for future work, additional improvements can be introduced, including the implementation of exact duplicate UAVs for each backup UAV (UAV_{sk}). The purpose of having duplicates is to address the issue of low battery in worker backup UAVs during mission. In this case, the working backup UAV could be replaced by its duplicate when needed, allowing them to exchange roles where the worker backup UAV becomes a backup (copy backup), and the duplicate takes over the operational task (worker backup UAV) keeping a seamless and uninterrupted connectivity .

Bibliography

[1] Arnold, P., Bayer, N., Belschner, J., & Zimmermann, G., "5G radio access," Conference on Networks and Communications (EuCNC) (pp. 1-5). IEEE, European, 2017, June.

[2] "qualcomm," [Online]. Available: https://www.qualcomm.com/news/onq/2024/03/6g-foundry-rethinking-the-control-plane. [Accessed March 2025].

[3] "3rd Generation Partnership Project (3GPP)," [Online]. Available: https://www.3gpp.org/.. [Accessed March 2025].

[4] "European Telecommunications Standards Institute (ETSI)," [Online]. Available: https://www.etsi.org/. [Accessed March 2025].

[5] "Open Networking Foundation," [Online]. Available: https://opennetworking.org/. [Accessed March 2025].

[6] "International Telecommunication Union (ITU)," [Online]. Available: https://www.itu.int/en/Pages/default.aspx. [Accessed March 2025].

[7] Sufyan, A., Khan, K. B., Khashan, O. A., Mir, T., & Mir, U., "From 5G to beyond 5G: A comprehensive survey of wireless network evolution, challenges," 2023.

[8] D. Camara, Public Safety Networks from LTE to 5G, 2017.

[9] R. Kamal, Mobile Computing and Wireless Networks. McGraw-Hill Education, India, 2015.

[10] Kodheli, O., Lagunas, E., Maturo, N., Sharma, S. K., Shankar, B., Montoya, J. F. M.,Goussetis,G., Satellite communications in the new space era, 2020.

[11] Wang, L., & Tang, H., Device-to-Device Communications in Cellular Networks, 2016.

[12] Wei, Z., Zhu, M., Zhang, N., Wang, L., Zou, Y., Meng, Z., Feng, Z,, "UAV-assisted data collection for the Internet of Things," *IEEE Internet of Things,* 2022.

[13] Fotouhi, A., Qiang, H., Ding, M., Hassan, M., Giordano, L. G., Garcia-Rodriguez, A., & Yuan, J, "UAV cellular communications: Practical aspects, standardization advancements," *IEEE communications,* 2019.

[14] Oubbati, O. S., Atiquzzaman, M., Ahanger, T. A., & Ibrahim, A., "Softwareization of UAV networks," 2020.

[15] Khuwaja, A. A., Gharavi, H., & Chen, Y., "Network Slicing Techniques for 5G and Beyond," 2020.

[16] Foukas, X., Patounas, G., Elmokashfi, A., & Marina, M. K., "Network slicing in 5G," *IEEE communications,* 2017.

[17] Gao, H., Liu, C. H., Wang, W., Zhao, J., Song, Z., Su, X., ... & Leung, K. K., "incentive mechanisms for participatory sensing," *IEEE Communications,* 2015.

[18] Zhen, Y., Khan, A., Nazir, S., Huiqi, Z., Alharbi, A., & Khan, S., "Crowdsourcing usage, task assignment methods, and crowdsourcing platforms: a systematic literature review.," *Journal of Software: Evolution and Process,,* pp. 33(8), e2368, 2021.

[19] T. Bouzid, "Resource slicing for UAVs communications," Department of Computer Science, University Amar Telidji of Laghouat, 2023.

[20] "5gworldpro," [Online]. Available: https://www.5gworldpro.com/blog/2020/11/23/how-does-5g-network-slicing-works/. [Accessed April 2025].