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THEME

Streaming in Swarm of UAVs and MEC assisted Networks

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بسم الله الرحمن الرحيم

DEDICATION

I dedicate this work to my loving family,
To the memory of my beloved mother,
To my affectionate father,
To friends and colleagues who are always there for me.
Rahil

ACKNOWLEDGMENTS

All my gratitude and thanks to Allah Almighty, who gave me strength, courage and will in light of the current circumstances to develop this work.

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I would like to show my sincere appreciation to the committee members, Dr. Younes Guellouma and Dr.Tahar Bendouma, I thank them for taking the time to consult my humble work, and I am looking forward to hear from them and consider their constructive critics and valuable advice to improve it.

I do not forget my gratitude to all the professors of the Computer Science Department, and thanks to everyone who contributed to the development of this work from near or far.

Rahil, June 2022

مُلَخَص

مع التطورات المستمرة في تقنيات الحوسبة والاتصالات الذكية في الماضي القريب، أصبحت الطائرات بدون طيار وحوسبة الحافة المتنقلة تلعب دورًا مهمًا في إنترنت الأشياء كأجسام ذكية، وقد تصبح طريقة مثيرة للاهتمام لتقديم خدمات إنترنت الأشياء الجديدة عند تجهيزها. تتطلب غالبية تطبيقات إنترنت الأشياء في الوقت الفعلي مثل خدمات بث الفيديو والمراقبة الزراعية وتطبيقات الأدوية قدرًا كبيرًا من الموارد وأجهزة إنترنت الأشياء التي لا يمكن تقديمها بواسطة مركبة جوية واحدة بدون طيار، لذلك، قد تتطلب خدمة إنترنت الأشياء الواحدة مشاركة سرب متعاون من الطائرات بدون طيار. في هذا العمل، ستتم دراسة البث المباشر مع مشكلة التوجيه في سرب من الطائرات بدون طيار وخوادم الحافه المتنقلة، والتي تهدف إلى توصيل المعلومات إلى أعضاء محددين في الطائرات بدون طيار المحمولة. تتمثل أهداف هذا العمل في (1) توفير تصنيف لبروتوكولات لأسراب البث الحالية مع مراعاة استراتيجيات النقل و (2) اقتراح تقنية بث جديدة تهدف إلى تقليل التأخير من البداية إلى النهاية للطائرات بدون طيار واستكشاف الشبكات بكفاءة والبحث مسارات التوجيه ثلاثية الأبعاد مع إنتاجية شبكة أعلى. تدعو نتائج المحاكاة التي أجريت باستخدام جهاز محاكاة Omnet++ إلى كفاءة طريقتنا من خلال نسختين مقترحتي (باستخدام بروتوكولات توجيه AODVوDSDV) من حيث تقليل التأخير من طرف إلى طرف وزيادة الإنتاجية.

الكلمات المفتاحية: الطائرات بدون طيار، سرب التعاونيات بدون طيار، تكنولوجيا إنترنت الأشياء، وحوسبة الحافة المتنقلة، خدمات البث المباشر، Omnet++

ABSTRACT

With the continuing advancements in smart computation and communication technologies in the recent past, Unmanned Aerial Vehicles (UAVs) and Mobile Edge Computing (MEC) play an important role in the Internet of Things (IoT) as intelligent objects, and they may become an interesting way to offer new IoT services when they are equipped with suitable IoT devices. The majority of IoT real-time applications such as, video streaming services, agriculture surveillance and medicine applications require high amount of resources and IoT devices that cannot be offered by a single Unmanned Aerial Vehicle (UAV), Therefore, a single IoT service may require the involvement of swarm of cooperatives UAVs. In this work, streaming with routing problem in swarm of UAVs and MEC servers will be studied, which aims at delivering information to specific members of mobile drones. The objectives of this work are to (1) provide detailed classification of existing streaming swarm protocols considering transmission strategies and to (2) propose a new streaming technique aiming to reduce the End-to-End delay of UAVs and efficiently explore networks and searching 3D routing paths with higher network throughput. The results of the simulation conducted using Omnet++ simulator advocate for the efficiency of our method through two proposed versions (using AODV and DSDV routing protocols) in term of reducing the End-to-End delay and increasing throughput.

Keywords : UAVs, Swarm of Cooperatives UAVs, IoT Technology, MEC, Video Streaming Services, Omnet++.

RÉSUMÉ

Avec les évolutions continus des technologies de calcul et de communication intelligents, UAV et MEC jouent un rôle important dans le IoT en tant qu'objets intelligents, et ils peuvent devenir un moyen intéressant d'offrir de nouveaux services IoT lorsqu'ils sont équipés d'appareils IoT adaptés. La majorité des applications IoT en temps réel telles que les services de streaming vidéo, la surveillance agricole et les applications médicales nécessitent une grande quantité de ressources et d'appareils IoT qui ne peuvent pas être offerts par un seul UAV. Par conséquent, un seul service IoT peut nécessiter l'implication d'un essaim de coopératives UAVs. Dans ce travail, le streaming avec le problème de routage dans un essaim de serveurs MEC et UAVs sera étudié, qui vise à fournir des informations à des membres spécifiques de drones mobiles. Les objectifs de ce travail sont de (1) fournir une classification détaillée des protocoles d'essaim de streaming existants en tenant compte des stratégies de transmission et de (2) proposer une nouvelle technique de streaming visant à réduire le délai de bout en bout des UAVs et à explorer efficacement le réseaux avec un routage 3D et un débit de réseau plus élevé. Les résultats de simulation réalisés à l'aide du simulateur Omnet++ montrent l'efficacité de notre méthode à travers de deux versions proposées (utilisant les protocoles de routage AODV et DSDV) en termes de réduction du délai de bout en bout et d'augmentation du débit.

Mots clés : UAV, Essaim de UAVs coopératifs, IoT, MEC, Services de streaming Vidéo, Omnet++.

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LIST OF ACRONYMS

A3C asynchronous advantage actor-critic. 21

ABR Adaptive Bit Rate. 24

AC Actor-Critic. 23

AODV Ad-hoc On-demand Distance Vector. 30, 32, 34, 37

BS Base Station. 19, 20, 21, 27, 31

CMDP Constrained Markov Decision Process. 21

CNPC Control and Non-Payload Communications. 6

CU cloud Unit. 19, 20

DES Data Encryption Standard. 22

DQN Deep Q-Network. 23

DRL Deep Reinforcement Learning. 21, 23, 24

DSDV Destination-Sequenced Distance Vector routing. 30, 32, 34, 37

DTMC Discrete-Time Markov Chain. 21

FEC Forward Error Correction. 19, 22

GBS Ground Base Station. 10, 11

GCS Ground Control Station. 5, 6, 7, 10

GPS Global Positioning System. 5

GTG Group-to-Group. 11

HAUs High Altitude UAVs. 8

IoT Internet of Things. v, vi, 11, 27

LAUs Low Altitude UAVs. 8, 9

LSTM Long Short-Term Memory. 24

MAUs Medium Altitude UAVs. 8

MDP Markov Decision Process. 21

MEC Mobile Edge Computing. v, vi, 1, 2, 4, 11, 13, 14, 21, 24, 27, 30, 38

OTT Over-The-Top. 17

PDR Packet Delivery Ratio. 25

QoE Quality of Experience. 17, 21, 23, 24, 25

QoE-AC QoE-Actor-Critic. 24

QoS Quality of Service. 2, 25

RAM Resource Allocation Model. 24

RSU Roadside Units. 13

SA-ABR Sensor-Augmented ABR. 24

SDMN Software-Defined Mobile Networks. 21

SDN Software-Defined Networking. 21, 24

SMS Splitting-Merging Stream. 22

SSA-UMN Streaming Swarm Approach in UAVs and MEC assisted Networks. 26

STR Stalling Time Ratio. 25

U2G UAV-to-Ground. 6

U2GCS UAV-to-GCS. 6

U2S UAV-to-Satellite. 6

U2U UAV-to-UAV. 6

UAV Unmanned Aerial Vehicle. v, vi, x, 1, 2, 4, 5, 6, 7, 9, 10, 11, 16, 22, 23, 24, 30, 31, 33, 38

UAV-UEs UAV Users. 23

UAV-BS UAV as Base Station. 23

UAVs Unmanned Aerial Vehicles. v, vi, x, 1, 2, 4, 6, 7, 9, 10, 11, 13, 14, 16, 23, 24, 25, 27, 28, 30, 34, 37, 38

UDP User Datagram Protocol. 22

VOD Video-On-Demand. 17

CHAPTER 1

INTRODUCTION

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1.1 Context

UAVs have been used by the military for mission-critical and wartime purposes for more than two decades. More recently, they have seen great advancements in structure, working technique, flying features, and navigation control. In addition, the collaboration between UAVs and MEC servers has drawn significant research interest because of the services it offers including search and rescue operations, managing wildfire, patrolling, delivery of goods, monitoring, surveillance, video streaming for live events, and video calls [4].

Carrying out a mission with a group of cooperative UAVs rather than a single UAV has attracted a lot of interest in order to execute a mission effectively and efficiently, When a group of UAVs is collaboratively structured, a swarm of UAVs is created.

A swarm is a group of behaving entities that work together to achieve a significant or desirable result. In nature, there are various examples of swarming activity. Bees work together to execute activities that are vital to the swarm's existence. To complete their voyage, flocks of migratory geese coordinate effective flight paths. A swarm of UAVs, on the other hand, is a coordinated group of UAVs that performs a certain mission or set of tasks.

However, it also poses many challenges in designing networking protocols such as, the 3D mobility of UAVs, which causes frequent changes in network topology.

1.2 Problem Statement and Motivations

As the technology of UAVs improves and their costs decreases, they become an interesting approach to tackle a variety of complex tasks, particularly when the drones form a swarm. Although the deployment of UAVs swarm has some appealing benefits, it also has many challenging characteristics that may affect the reliability and stability of these networks. To support their various services, it is necessary to design efficient routing protocols according to the targeted missions. To this end, many swarm routing protocols have been proposed and studied for streaming services, which can be divided into two main classes: (i) caching based methods [2, 3, 5] and (ii) artificial intelligence based techniques [6, 7, 8]. In this work, we interest to the second category. The solutions presented in this category do not address Quality of Service (QoS) requirements such as delay and throughput. Therefore, we attempt to design a new efficient MEC-based solution using a swarm of UAVs for improving the quality of service and experience in video streaming for rescue operations in wildfire and also for recreational services such as watching live events.

1.3 Organization of the Memoire

Our memoire is organized as follows:

- **Chapter 2** introduces UAVs and discusses their types. It also gives an overview of swarm-based systems and their main architecture and discusses the architecture of the MEC.
- **Chapter 3** concerns the presentation of streaming video with it's main streaming applications in UAVs and the state-of-the-art in which we illustrate different streaming adaptation techniques detailed description and comparison of discussed techniques.
- **Chapter 4** presents our streaming method in a swarm of UAVs. It is based on streaming using a token where every UAV streams in a slot-time.
- Finally, we conclude the work with a conclusion and some future perspectives.

CHAPTER 2

SWARM OF UNMANNED AERIAL VEHICLES AND MEC ASSISTED NETWORKS : BACKGROUND

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2.1 Introduction

More recently, Unmanned Aerial Vehicles (UAVs) have attracted interest research in civilian and military services, including search and rescue, wildfire management, agricultural applications, monitoring, and surveillance. Swarms of could UAVs improve the efficiency of these services much more. For instance, the ability to expand mission coverage and increase operation performance through multi-UAVs collaboration.

This chapter discusses the background of UAVs including their categories, focusing on their civilian uses. Then studying the swarms of UAVs, their applications, features, and challenges. After that, a presentation of video streaming types and challenges that affect the quality of experience. Closing with a study of MEC architecture and advantages.

2.2 Unmanned Aerial Vehicle System

Unmanned Aerial Vehicle (UAV), also known as drone, refers to an aircraft without a pilot on board that can fly autonomously when equipped with an onboard autopilot or can be remotely piloted from a ground station. It overcomes the limitation of the terrestrial system in terms of accessibility, speed and reliability.

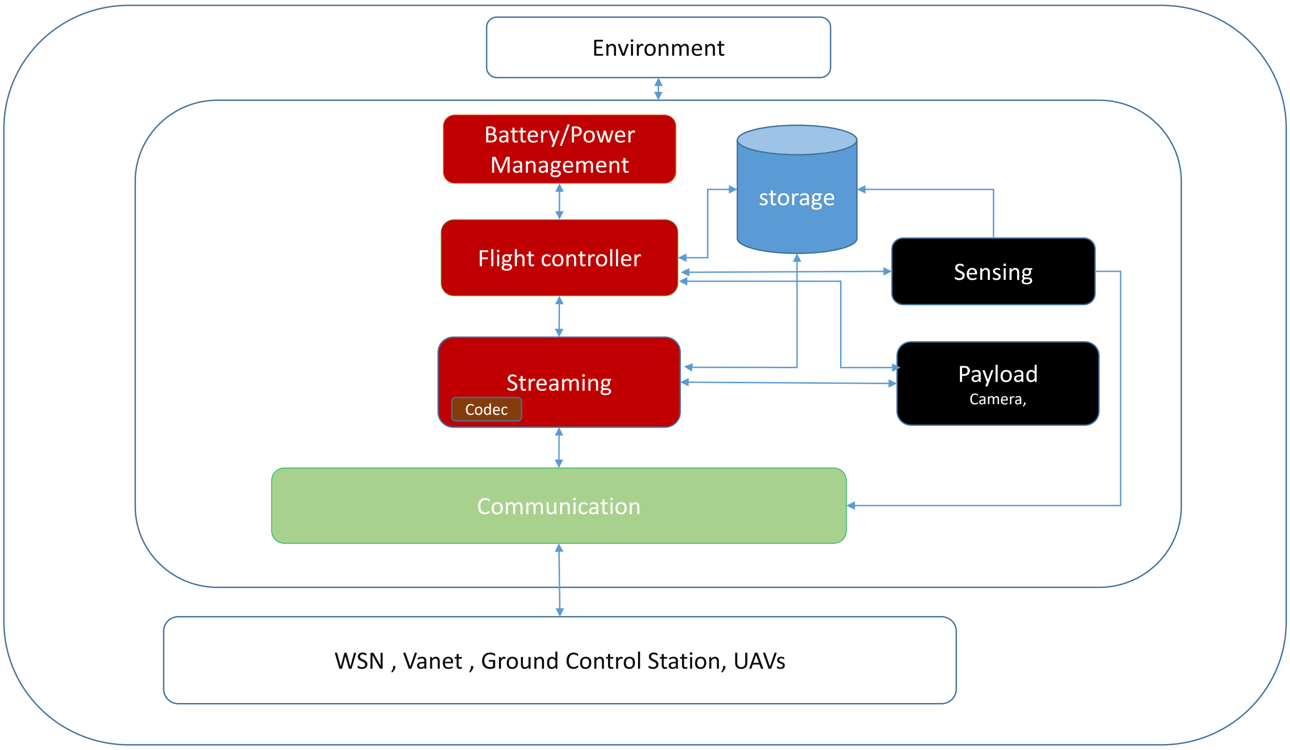


Figure 2.1: UAV Communication System Components

In addition to the classical components (propulsion system, motor,...etc.), the other components of a UAV system are shown in Figure 2.1 [9].

2.2.1 The Flight Controller

Also known as the micro-controller, is the essential component that controls all of the functions of a UAV, including backup, way-points, autonomous operations,...etc. The micro-controller receives the signals from different onboard sensors such as the Global Positioning System (GPS), accelerometer, gyroscope, radar, sonar, and thermal Sensors [9].

2.2.2 The Ground Control Station

Because UAVs are pilotless, many UAVs are handled remotely by a ground control station which is considered as the center that manages missions. It consists of computer software that gathers status information received from the UAV such as UAV's velocity, attitude, height, position and roll, among other features. The UAV and payloads are also controlled by the Ground Control Station (GCS) unit. To communicate and receive data from the UAV to the GCS, a radio frequency transmission is needed, with two important links: data link and command (control) link. The data link frequency is determined by the UAV type and functionality, in lower frequencies, penetration into obstacles will be greater, it means that the wavelength is longer. Communication link can send control commands from the GCS to the UAV and receive data about the flight on downlink. The data link usually works from 150 MHz to 1.5 GHz frequency range, and ensures the transmission of data between the UAV and GCS. The command link uses 2.4 GHz frequency, which is used to control the operation of UAV. The UAV scans the frequency within the 2.4 GHz, and ultimately selects the narrow-band frequency being unused by another UAV so many UAVs can use within 2.4 GHz frequency at the same time. For example using 2.4 GHz for UAV control and 5 GHz for video transmission will offer the user a range of about 4 miles, but, if using 900 MHz for UAV control and 1.3 GHz for video, a distance of 20 miles and more can be achieved [9].

2.2.3 The Power Module

This module regularly supplies all the different components of the UAV by the necessary energy in order to enhance the overall performances such as the flight time, speed and endurance.

2.2.4 Payload

It is the weight that an UAV can carry such as missiles in military UAVs, or packages for delivery in civiL applications.

2.2.5 The communication module

Different architectures could be used to ensure the communication between drones and between drones and GCS. There are four main types of UAV communication: (i) UAV-to-UAV (U2U) used for data and control links, (ii) UAV-to-GCS (U2GCS) for control and commands link, (iii) UAV-to-Ground (U2G) wireless nodes for UAV data transmission and collection, and (iv) UAV-to-Satellite (U2S) system.

Figure 2.2 shows the basic networking architecture of wireless communications with UAVs, which is composed of two types of communication links: the Control and Non-Payload Communications (CNPC) link and the data link.

The primary CNPC maintain a direct links between GCS and UAVs, they are preferable for delay reasons and generally used when UAVs take off and land, secondary CNPC links through satellite might be used as a backup to improve reliability and robustness. The CNPC is used for the safety of UAVs via real-time control, obstacle avoidance and collision avoidance techniques, as well as giving reliable information for UAV operations. The data is transferred in CNPC link in different communication types such as U2U and U2GCS [10].

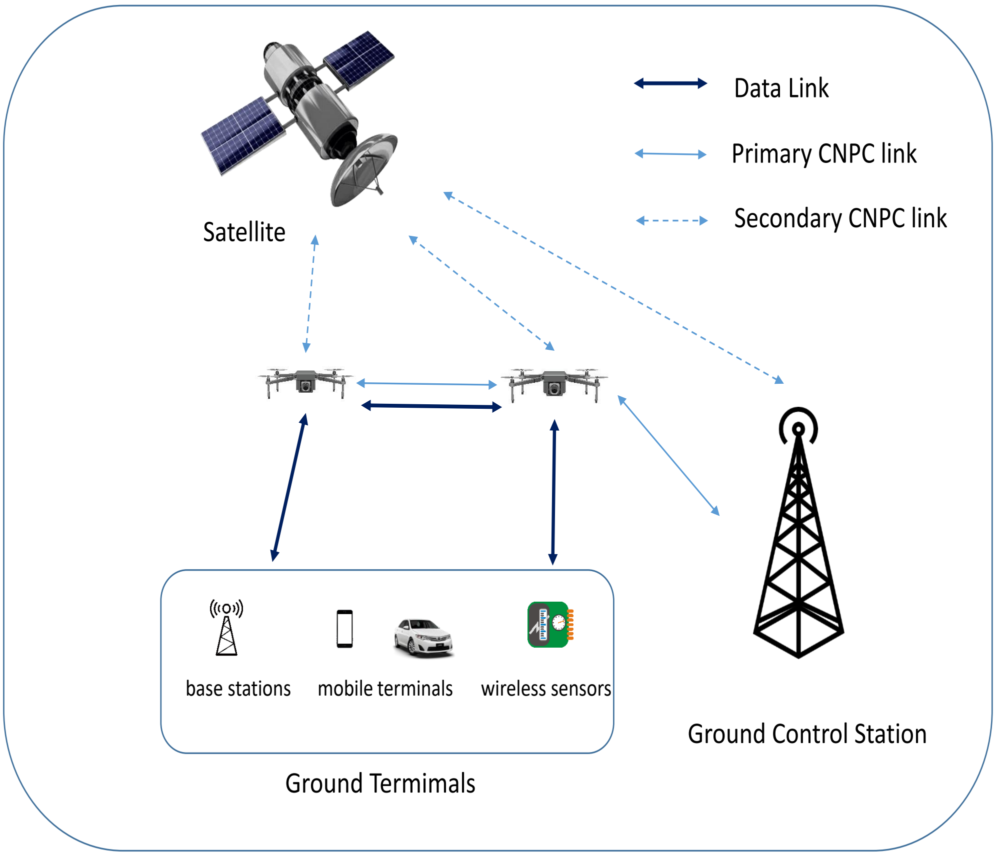


Figure 2.2: Architecture of Wireless Communications with UAVs

2.2.6 The streaming module

It utilizes the encoder to compress and encode the raw audio and video data from the microphone and camera. Then, the data is encapsulated according to the negotiation between UAV and GCS codecs into H.264 or H.265, etc. Streaming raw may stored in the cache or in the storage device for later use.

2.3 Types of UAVs

It is hard to achieve a unique classification for UAVs. Each classification in literature depends on some parameters such as flight altitude, payloads, the weight and size of the drones, flight range, endurance, speed, wings,...etc.[11]. Generally, Drones are classified into three types as shown in Figure 2.3.

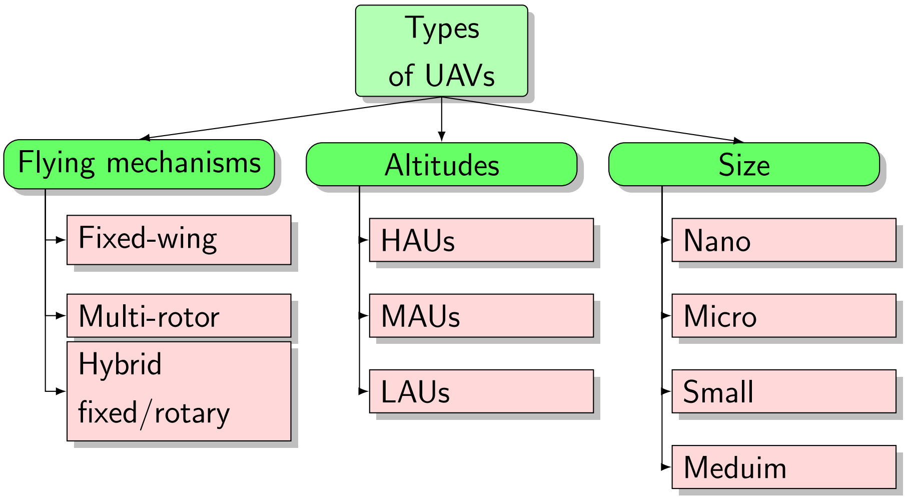


Figure 2.3: Classification of UAVs

2.3.1 Flying Mechanisms

Fixed-wing, multi-rotor, and Hybrid fixed/rotary wing. Multi-rotor drones (also known as rotary-wing drones) allow vertical take-off and landing, have limited mobility, and consume a lot of power because they have to fight gravity all the time. They are commonly used in aerial photography and video aerial inspection, agriculture, construction, and security, but due to the limited flying time and endurance speed, they are not suitable for aerial mapping or surveillance [12] [11]. Fixed-wing drones can glide through the air, improving energy efficiency and allowing them to transport a large payload. Fixed-wing drones, which are commonly employed in aerial mapping, agriculture, construction, and inspection, may also glide to go quicker. Fixed-wing drones have the disadvantages of (i) needing a runway to take off and land since vertical take-off and landing are not possible, and (ii) being unable to hover over a fixed location because they only move forward. Drones with fixed wings cost more than those with multiple rotors. Hybrid fixed/rotary wing drones have recently entered the market to give a compromise between the two drone kinds stated above, which can take off vertically, glide through the air to reach their target fast, and then hover using four rotors.

2.3.2 Altitude

They could be divided into three categories: (i) High Altitude UAVs (HAUs), (ii) Medium Altitude UAVs (MAUs), and (iii) Low Altitude UAVs (LAUs). The term ”altitude” refers to a drone’s maximum height. HAUs, such as airplanes, and hot air balloons, have a height of more than 20 kilometers and are almost stable. MAUs fly at a medium altitude of roughly 11 km, similar to airplanes, and there is an immediate change in certain viewpoints from base nodes. LAUs reach a range of kilometers and represent very mobile devices such as drones [12].

2.3.3 Size

It can be varied from nano with 200g to micro and mini which are less than 2Kg and 20 Kg respectively to small which are less then 150 Kg.[13]. Furthermore, their **speed** could be varied from 15 m/s or less for the small UAVs and 100m/s for big UAVs. The **endurance** of small commercial UAVs is about 20-30 minutes, while larger drones can fly for hours. Small UAV durability has been extended due to advanced technology such as Skyfront Tailwind which can fly for up to 4.5 hours [11]. The last two characteristics can be regarded as supplementary classification criticisms, Because they changed according main classification criticisms in Figure 2.3.

2.4 Swarm of UAVs

A swarm of UAVs is a group of aerial drones that collaborate to accomplish a shared goal. This term is inspired by the behavior of birds, fishes, and insects when they are travelling in groups following the same pattern to solve a difficult optimization issue. It is recommended to use a group of UAVs since it addresses the limits of single UAV systems, such as limited payload and flight time.

2.4.1 Need for Swarm Communication

With the advancement of both embedded and micro-electro-mechanical systems, it is possible to produce small UAVs at a low cost and have them work in groups in a coordinated and collaborative manner to form a multi-UAVs system. Furthermore, the capacity to swarm a large number of UAVs to complete complex tasks becomes appealing since it addresses the limits of single UAV systems, such as payload and flight time. It also has other features and benefits, such as time savings, reduced labor, and lower operational costs. If the UAV or a sensor/hardware fails in a single UAV system, the UAV should return to the base. However, in swarm-based systems, other collaborative UAVs have the ability to share tasks among themselves and this increases the fault tolerance of the system. For instance, in search missions, a collaborative group of UAVs can parallelize individual tasks, reducing mission completion time, increasing coverage range, and providing real-time photos and videos, which can help improve the operation's quality.

2.4.2 Swarm Communication Architecture

In the intelligent control of collaborative swarm of UAVs, communication architecture is critical. In this subsection, we will introduce some of the most typical communication designs for UAV swarm systems. We also discuss the architecture's advantages and disadvantages, as well as its structure and organization [14] [15].

- **Centralized Communication Architecture:** Inspired by the single UAV communication it consists of an infrastructure which is Ground Base Station (GBS) that receives data from all drones in the swarm and send back response to each UAV independently. The benefit of this architecture is that optimization and calculations may be executed in real-time by a GCS. Furthermore, there is no need for drones to communicate with one another, resulting in a lower payload need. However, as the number of UAVs grows, designing an appropriate network architecture becomes a difficult task, several design restrictions may occur. Since it is centralized all the UAVs should communicate the GCS which is a single point of failure that may impact the entire network if it breaks. Also, the transmission of data between UAVs necessitates to go throw the infrastructure, causing longer delay.

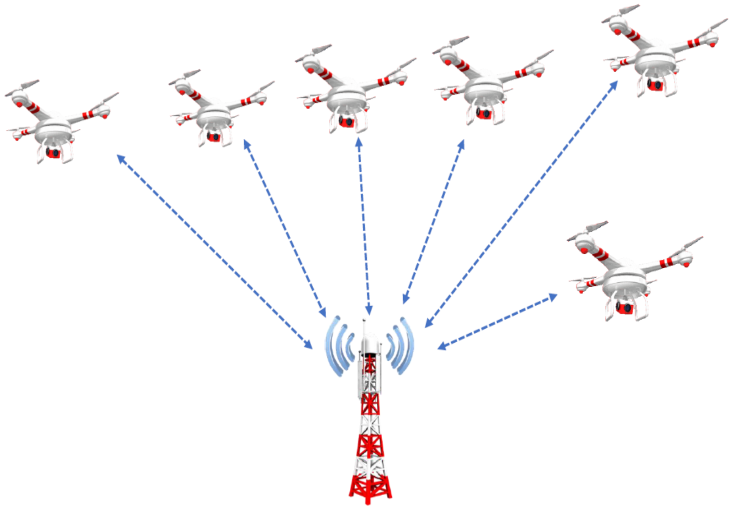


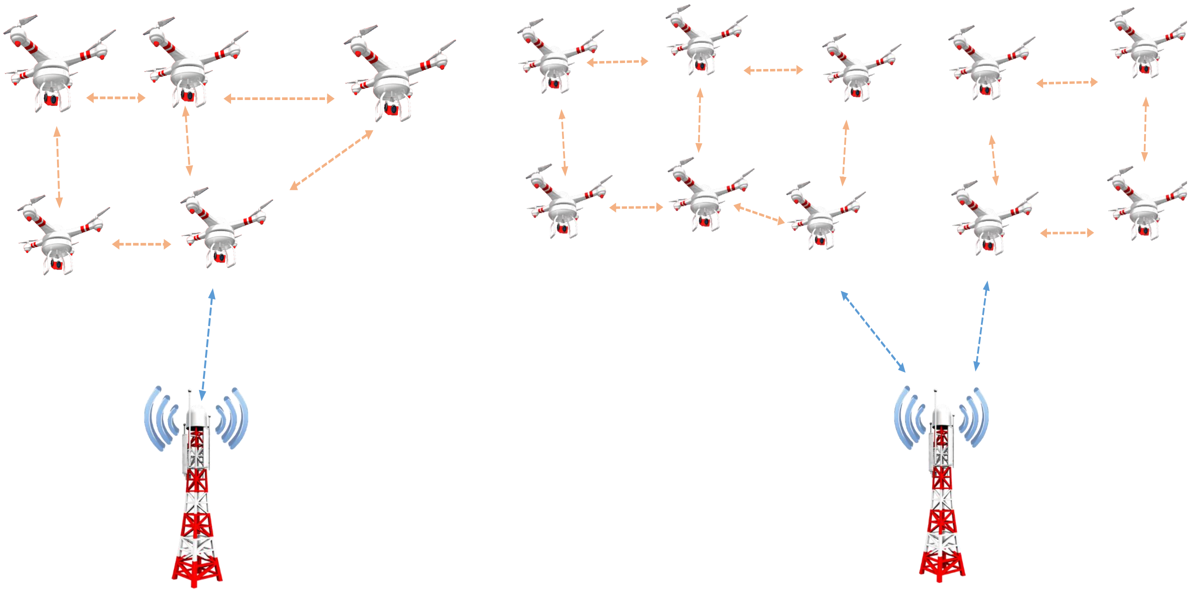
Figure 2.4: Centralized swarm architecture

- **Decentralized Communication Architecture:** UAVs regularly connect and disconnect from the network because of their rapid speeds and the fact that their missions may cover wide areas. The UAV swarm ad-hoc network is considered to be the most suitable choice, where all the UAVs can communicate each other directly or indirectly to perform real-time interactivity, without relying on infrastructure and communication range limitations. Decentralized communication architecture comprises the following schemes:

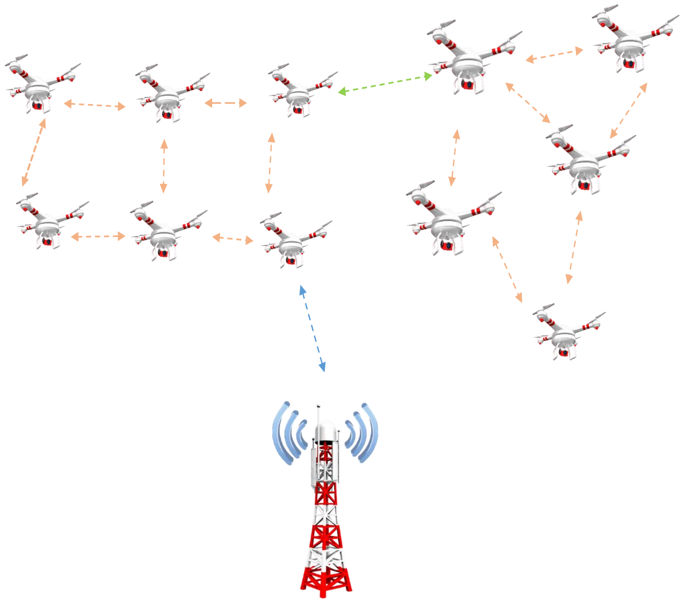
1. **Single-Group Swarm Ad-hoc Network:** In this architecture (Figure 2.5a) the internal communication of the swarm is not dependent on the infrastructure, but one of the UAVs called gateway must be connected to the GBS.
2. **Multi-Group Swarm Ad hoc Network:** As shown in the Figure 2.5b, this architecture combines both a centralized and a "single-group swarm Ad-hoc network" design to overcome the disadvantages of a "single-group swarm Ad-hoc network". Inter-group communications, also known as Group-to-Group (GTG) communications, are handled by the GBS, therefore the gateway UAVs are responsible for communicating with it.
3. **Multi-layer Swarm Ad hoc Network:** Is ideal for a wide range of UAVs. As illustrated in Figure 2.5c, this architecture is much more advanced than the "multi-group swarm Ad-hoc network" architecture. An Ad-hoc network is the first layer of the communication architecture, consisting of a group of UAVs of the same type. Different types of UAV groups rely on gateway UAVs to execute GTG communication, which is the second layer. The infrastructure, which is the third layer of the architecture, is communicated with by the nearest gateway UAV. Communication between two UAVs from different groups does not need to connect the GBS.

2.5 MEC

According to the Cisco Visual Networking Index [16], there were 18.4 billion connected devices in 2018, and it predicts that by 2023 there will be 29.3 billion, which is more than three times the global population. By 2021, video and live streaming represented more than 77 % of all mobile network bandwidth, with an average mobile user downloading 1TB of data in 2020 [17]. The usual centralised architecture of mobile cloud computing would be incapable to cope with the large-scale data. With the appearance of 5G and IoT the centralized mobile cloud computing have changed to MEC to bring computing and storage resources closer to wireless end devices physically, so computation-intensive and latency-critical applications may run on mobile devices with limited resources [18, 19].



(a) Single-Group Swarm Ad hoc Network (b) Multi-Group Swarm Ad hoc Network



(c) Multi-layer Swarm Ad hoc Network

Figure 2.5: Different Decentralized Architecture Forms

2.5.1 Architecture of Mobile Edge Caching

Mobile edge caching is part of Mobile Edge Computing (MEC) which uses the storage provided by mobile edge servers to cache the content, as seen in Figure 2.6, the architecture is composed four layer that are explained below:

- **Application layer:** Contains the mobile application that require intensive data such as streaming and gaming.
- **User node layer:** Is composed of devices and physical objects, such as mobile phones, tablets, and any smart device. They could be a data requesters or data providers.
- **Edge server layer:** Is responsible to deliver the data to user nodes in edge areas. The edge caching servers are usually located in cellular network base stations, Roadside Units (RSU), Wi-Fi access points, UAVs, and other access network infrastructures. It's main characteristics are storage capacity and coverage radius.
- **Cloud service layer:** Provide backup to end users when the edge servers are unable to satisfy data demands due to the limited resources.

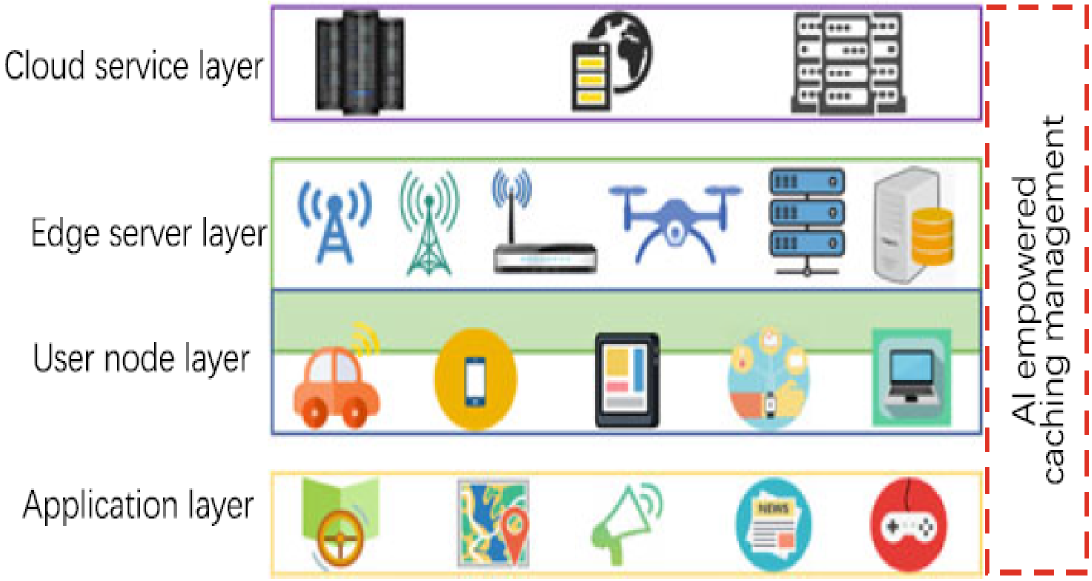


Figure 2.6: Architecture of mobile edge caching [1]

2.5.2 Need for Using MEC

Because of the high computation complexity of streaming tasks and the limited capabilities of UAVs, it is preferable to use MEC to improve the communication and processing capabilities, by (i) offering a real-time interaction between MEC server and end devices, (ii) reducing latency of the energy consumption of end devices, communication, and computation, and (iii) enhancing the confidentiality of users by operating their needs privately.

2.6 Conclusion

This chapter presented a background on UAVs, with the main characteristics, challenges, communication architectures, and applications of swarm UAVs. Moreover, it shows the fundamental benefit of using the MEC architecture. The next chapter will present and analyze the existing streaming adaptation techniques.

CHAPTER 3

STREAMING IN SWARM OF UAVS : STATE OF THE ART

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3.1 Introduction

Within the industrial and academic research topics, video streaming is still gaining a lot of popularity for mobile consumers. Furthermore, providing streaming services on UAVs has a number of issues, such as adapting to the time and quality limits imposed by the nature of multimedia data on one hand, and giving the user a reliable packets on the other.

In the field of video stream enhancement and adaptation, there have been a lot of works published. Yet, each group of them focused on a specific topic in this large domain, knowing that the study of video stream in UAVs is a new trend with a bright future but which has yet to be fully utilized. In the rest of this chapter, we briefly summarize the different recent works on streaming video optimization.

3.2 Video Streaming

Streaming is a technique of Media transfer in the form of a continuous process that can be processed by the client's computer in real time, without waiting to receive the totality of the file sent from the server [20]. According to Statista, in 2021, worldwide viewers spent an estimated 548.7 billion hours on live streaming applications [21]. Multimedia communication, particularly video streaming, is important for surveillance, entertainment, and emergency applications.

3.2.1 Applications of Streaming in UAVs

UAVs were mostly used for military purposes until recently, but they are increasingly being used for a wide range of recreational and civilian purposes.

Figure 3.1 shows the different application that a UAV could use especially in the streaming field, We have gathered a list of the most popular streaming swarm-oriented applications, as follows:

- **Search and Rescue:** A swarm of UAVs is ideal for covering large geographical areas in a short time. For instance, a collaborative swarm of UAVs is helpful in the search for people who are in trouble or are in imminent danger. The real-time images can provide a view of the inaccessible places resulting in a gain of time, and saving more lives.

- **Remote Sensing:** In this field, a swarm of UAVs could be used to manage disasters such as forest fire warnings by enabling direct image wildfire mapping and surveillance, This would allow incident teams to have a better understanding of the fire situation and allow them to optimize firefighting resources. In the same frame it could be used for tracking animals and patrol borders, ...etc.

- **Live Event:** A wide range of events that UAVs could be used in such as sport events, concerts that are not available on broadcasting channels.

Figure 3.1: Different Applications for Swarm of UAVs

3.2.2 Types of video streaming

There are many different types of streaming video applications available. The following represents the twho main types of video streaming [20].

3.2.2.1 VOD Streaming

Video-On-Demand (VOD), also know as Over-The-Top (OTT) streaming, it allows watching the video on the Internet at any time in real-time where the video contents are already stored in servers and are streamed to viewers upon their requests. VOD is the most popular sort of video streaming, and it's available from major video streaming providers like YouTube, Netflix, Apple TV+, dailymotion, and many other services [22].

3.2.2.2 Live Streaming

Live streaming is a technique that allows customers to receive video streams in real-time as they are taken by a camera. This type is frequently used for live events, video calls and surveillance. The main factor that affects Quality of Experience (QoE) of live video streaming is the buffer size for sender or receiver. The video stream becomes more stable as the buffer size increases. However, as result that causes more transmission latency. Even so, live broadcasts usually have some initial delay to avoid the jitter. live streaming can take four different forms [23, 22]:

1. **One-to-one:** Also known as unicast or point to point communication requires the server to duplicate a video stream for each end user, it wastes bandwidth by transmitting multiple copies of data across the server to various clients. This kind is commonly used in video call applications that require two live streams from each participant, these applications use a small buffer size and low picture quality to keep the delay to a minimum.
2. **One-to-many:** Also called multicast, the server only sends a single stream to a group of users that are registered in a multicast group. usually used in video-conferencing applications, this technique is available on lots of social media platforms such as Facebook and Instagram.
3. **Many-to-one:** Refers to when multiple cameras record scenes and send them to one viewer. The basic application for this form of streaming are situational awareness for security purposes and natural disaster management.
4. **Many-to-many:** Streaming takes place when a group of users in different geographic regions holds a video so all users broadcast live to everyone else. Video chat applications can provide this service in addition to one-to-many.

3.2.3 Metrics of Video Streaming

1. The **end-to-end delay :** is the time taken to transfer a packet from its sending source to its receiving destination. This delay for each packet is calculated following this formula:

   Delay = (reception time of the packet) – (delivery time of the packet)

2. The **bandwidth :** available between two points on the Internet is usually unknown and varies over time. If the sender transmits at a quicker rate than the available bandwidth, congestion occurs, packets are dropped, and video quality decreases. When the transmitter transmits at a slower rate than the available bandwidth, the video quality at the receiver decreases. To solve the bandwidth problem, first estimate the available bandwidth, then match the sent video bit rate to that capacity. It could be calculated as the following formula:

   Bandwidth = received data size (bps)/ end-to-end delay of the packet

3. **Jitter :** refers to the variance in end-to-end delay. the receiver must receive frames at a consistent rate, and any late frames caused by delay jitter can create issues with the rebuilt video. A playout buffer at the receiver is usually used to solve this problem. It could be calculated as followed :

   Jitter=(end-to-end Delay max) – (end-to-end Delay min)

4. **Loss rate :** when an entire packet is lost or some bit errors depending on the network situation. A video streaming system with error control is designed to minimise the impact of losses such as Forward Error Correction (FEC) and re-transmissions. It could be calculated as followed :

   Loss rate = number of loss packet / total transmitted packets

5. **Quality of Experience :** is a user-centric metric that measures performance from the user's perspective for satisfaction, effective network and service quality .

3.3 Enhancement of video stream techniques : Related work

Recently, many studies have been presented in the literature, ranging from Artificial Intelligence (AI), deep learning, neural networks, and edge caching. In this section, we will focus on the articles dealing with caching that we can classify into two categories:

1. Caching at the end-user (buffering).
2. Caching at the infrastructure.

In addition, we will highlight the techniques to improve streaming through artificial intelligence.

3.3.1 Caching Based Techniques

1. Jeongho Kwak et al. proposed in [2] a hybrid content caching architecture that does not depend on content popularity information, which optimizes content caching locations that might be original content servers, central cloud Unit (CU)s, and Base Station (BS)s, with the aim of supporting the highest average requested content data rates acceptable while reducing service latency. The design was implemented using an optimization strategy (Lyapunov strategy) to solve an NP-hard caching control by integrating CU and BS caching control decisions without the knowledge of past or far future content popularity profiles and network conditions. The proposed algorithm

was implemented in three specific caching scenarios and one general caching scenario resolved using heuristic algorithms.

(a) Single CU caching and homogeneous content size.

(b) Single CU caching and heterogeneous content size.

(c) Hybrid CU and BS caching, and homogeneous content size.

The last two scenarios ((b) and (c)) are NP-hard, thus, they propose approximation algorithms that achieve constant approximation ratios to the optimal weights by exploiting the sub-modularity of the slot-by-slot objective function and specific structure of the hierarchical content caching system. A virtual Queue is used for each BS to cache a single file for each cached content from which it can serve all requests relating to the underlying content, the architecture details are shown in figure 3.2.

- **Advantages**: This method reduces latency by optimizing the content caching location.
- **Drawbacks**: It does not take into consideration power consumption.

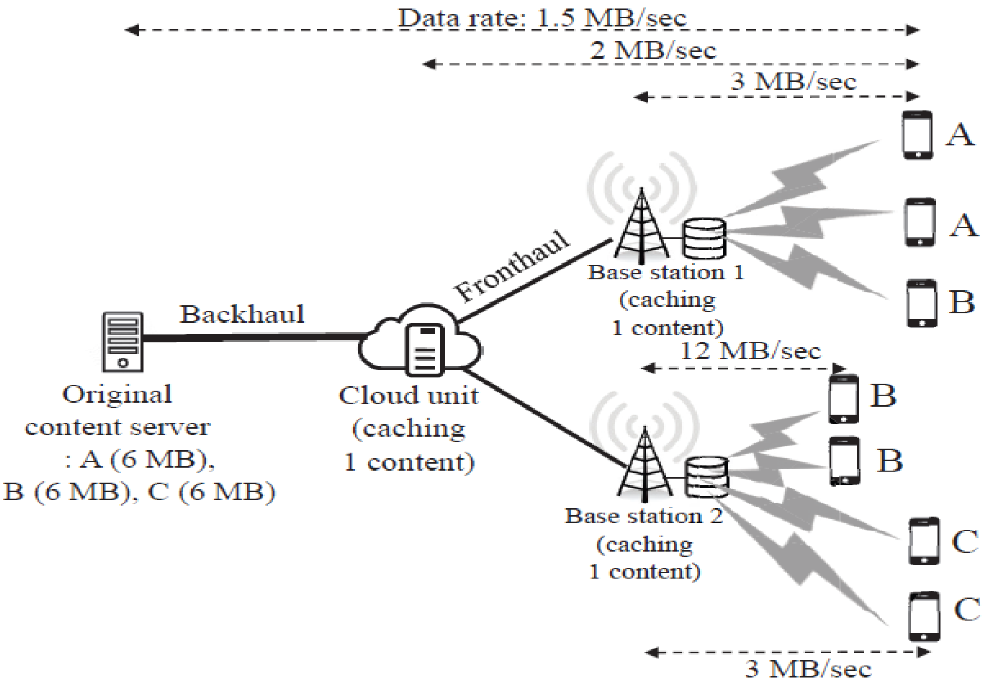

Figure 3.2: content caching architecture [2]

2. To optimize energy consumption and QoE video streaming, Software-Defined Mobile Networks (SDMN) combined with MEC is presented by Jia Luo et al. [3], while taking into consideration: buffer dynamics, video quality adaptation, edge caching, video transcoding, and transmission. At first, the time-varying channel is assumed to be a Discrete-Time Markov Chain (DTMC). after that two optimization problems based on this assumption are used: a Constrained Markov Decision Process (CMDP) and a Markov Decision Process (MDP). Then, using the Lyapunov approach, the CMDP issue is converted to a standard MDP problem. To solve the associated MDP difficulties, a model-free Deep Reinforcement Learning (DRL) technique is used which is the asynchronous advantage actor-critic (A3C) .

   Figure 3.3 shows the network architecture where the source of the video is the remote content data center and some of switch nodes in the MEC (mobile edge cloud) serve as service entry points, collecting user requests from access networks and serving them. The network operator creates virtual appliances to execute video transcoding and caching by renting relevant resources from resource pools and attaching them to any group of those switch nodes. To absorb the difference in video bit rate and available resources a buffer is used for each mobile device, a partial synchrony method is adopted to process the segments in a way that the mobile devices in the same BS are arranged into ascending order according to their buffer size to process each segment. The Software-Defined Networking (SDN) controller is the responsible to decide whether or not to transcode the segment that will be transmitted, determine the target bitrate of the segment in queue, and to assign the bandwidth and transmission power to the mobile device for video transmission during a processing period.

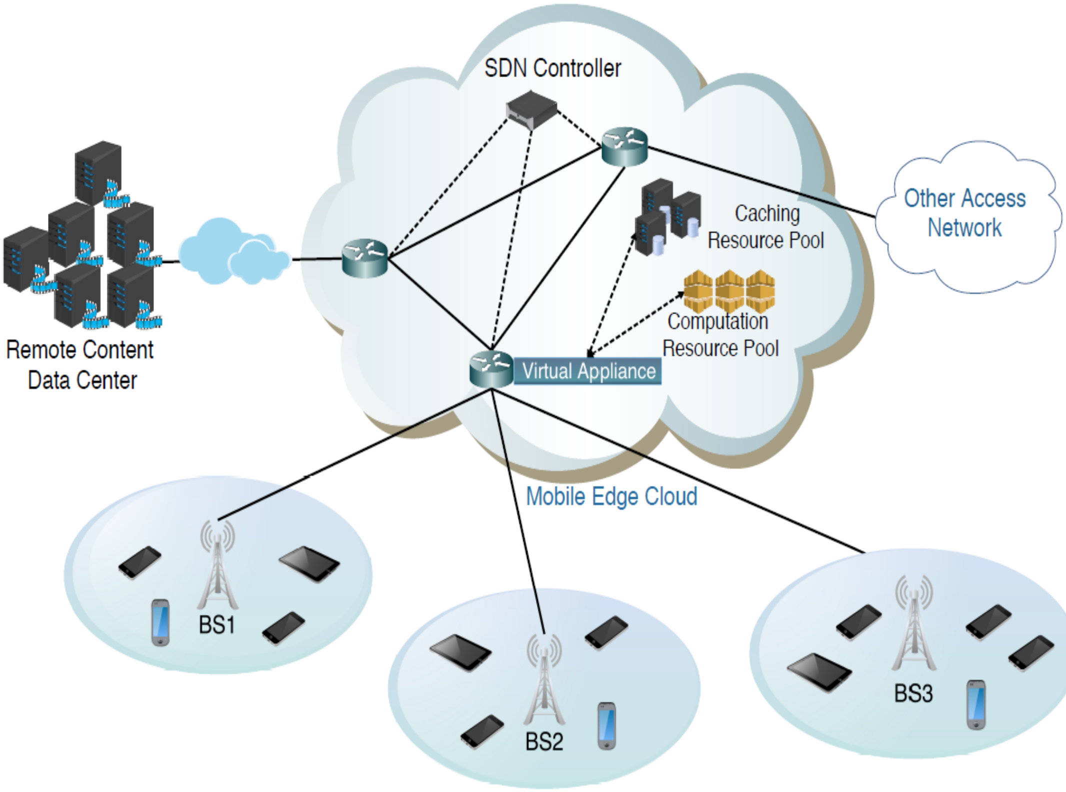

Figure 3.3: content caching architecture [3]

- **Advantages**: This method optimizes energy consumption and QoE video streaming metrics.
- **Drawbacks**: It is a centralized architecture that may cause some latency.

3. Zhichao Liu et al. [24] presented a Client-Server-Ground & User structure and a Splitting-Merging Stream (SMS) method for multi-link concurrent transmission, creating multiple data connections protect the transmission from a complex network situation and increase transmission reliability, and the SMS solve the heavy load and large delay problems due to the mobility of UAV and the unstable streaming transmission conditions, the UAV split a single stream into two streams based on their sequence number. as well as using FEC and Data Encryption Standard (DES) techniques to correct for RTP packet loss during User Datagram Protocol (UDP) transmission. In addition, an adaptive QoS evaluation algorithm on an engineering platform allow the UAV to modify dynamically the streaming modes (RTP, DES-RTP, FEC-RTP, and DES-FEC-RTP) by human control and automatic control from the QoS tool or the server.

   - **Advantages**: Loss tolerance using FEC, security due to encryption.

- **Drawbacks**: Single point of faillure using one UAV.

4. Caching content at the edge of mobile networks is being touted as a practical solution to the data flood, where users can prefetch video chunks into their playout buffer from nearby vehicle caches or stream from the cellular infrastructure. In this context, the aim of Luigi Vigneri et al. [5] is to model the playout buffer in the user device as a queueing system, and analyze the expected quantity of offloaded data (downloaded from the infrastructure) corresponding to its idle times as a function of network characteristics (vehicle density, file characteristics) and a particular cache allocation optimized to reduce the amount of non-offloaded bytes. The network architecture consists of three types of nodes:
   (i) Nodes of infrastructure such as Macro-cells or base stations offer full coverage and can satisfy any content request.
   (ii) Helper nodes could be a Car, bus, taxi, truck,...etc. They are used to store popular content and serve low-cost user queries through a direct vehicle-to-mobile node link.
   (iii) End-user nodes are mobile devices like Smartphones, tablets, and netbooks. These nodes make requests for (non-live) video content to be streamed to Helper and infrastructure nodes.
   Each video is composed of a series of small chunks that are sequentially downloaded into the playout buffer of a user node and consumed for playback from the infrastructure or helper nodes. In case the user node is in the range of a helper node that contains the requested content, the next immediate chunks not yet in the playout buffer are downloaded at a low cost in sequence at a mean rate. The download rate distribution and mobility statistics may easily estimate this mean rate, which is dependent on the cell association protocol utilized.

   - **Advantages**: Using two caching levels which perform the Network capacities.
   - **Drawbacks**: In sparse the performance decreases.

3.3.2 Artificial Intelligence Based Techniques

In this section, we will summarize a list of the main AI researchs and we will discuss the solutions that deal with DRL.

1. Liyana Adilla et al. [6] proposed a new streaming solution to maximize the QoE of real-time video streaming by designing (i) video resolution, (ii) movement of UAVs, and (iii) power control of UAV as Base Station (UAV-BS) and UAV Users (UAV-UEs) using Deep Q-Network (DQN) and Actor-Critic (AC) which have better results compared to the greedy algorithm.

2. Xiao el al. in [7] introduced a new sensor-augmented system that develops Adaptive Bit Rate (ABR) video streaming algorithms with the use of several types of intrinsic sensor data utilized to pilot UAVs in this study. Sensor-Augmented ABR (SA-ABR) Builds a deep DRL model to extract important characteristics from flight status information and automatically learn an ABR algorithm to adapt to varying UAV channel capacity over the training process by merging intrinsic sensor data with network observations. SA-ABR makes judgments by using temporal features of historical throughput through the Long Short-Term Memory (LSTM) to adapt to a wide range of highly dynamic settings, rather than relying on assumptions or models about the UAV's flying states or the environment.

3. When a big number of users play 3D video they put the cloud server under a lot of computational pressure, resulting in long transmission times. To alleviate the pressure, Pan Zhou et al. proposed in [8] a novel Resource Allocation Model (RAM) to allocate resources and decrease latency, which incorporates MEC and SDN, at the same time they offer the Quality of Experience QoE Model, which adapts the rate of future tiles based on data gathered during 3D movie watching. When there are time-varying characteristic variables during transmission, the model handles the problem of allocating the optimal transmission speed to the block. For viewport prediction and QoE optimization, they present QoE-Actor-Critic (QoE-AC), an Actor-Critic-based deep reinforcement learning for QoE optimization algorithm. Moreover, employing the LSTM network for bandwidth and viewport prediction in the playback phase, while incorporating the historical information from the blocks into the Actor-Critic network as observations. Further, To enhance QoE the network can adaptively assign the optimum transmission speed for future tiles depending on observations.

- **Advantages**: AI based solutions can reduce efficiently services costs and improve the effective data acquisition and analysis of scalable system.
- **Drawbacks**: Most of the previous techniques used LSTM which is an old technique based on the prediction and it is hard on UAVs due to their 3D mobility and the DRL techniques consume a lot of computation resources. In addition, the major limitation of using AI techniques is the need of the storage capacity.

3.4 Comparison and summary

Table 3.1 summarizes the main characteristics of the discussed methods, we focus on comparing the existing works that enhance the quality of video stream based on the type of video (live or stored), the used technology (5G in case of using the edge caching), QoE like Stalling Time Ratio (STR) and QoS needs such as and Packet Delivery Ratio (PDR). The solutions presented in Table 3.1 do not address QoS requirements such as delay and throughput. Therefore, we attempt to design a new efficient MEC-based solution using a swarm of UAVs for improving the quality of service and experience in video streaming for rescue operations in wildfire and also for recreational services such as watching live events.

Table 3.1: Comparison related works

Methods	**using UAV**	**Live Video Stream**	**Edge caching**	**Popularity**	**STR**	**PDR**
[2]	✗	✗	✓	✗	✗	✗
[3]	✗	✗	✓	✗	✓	✗
[5]	✗	✗	✓	✓	✗	✗
[24]	✓	✓	✗	✗	✓	✓
[8]	✗	✗	✓	✗	✓	✓

CHAPTER 4

STREAMING SWARM APPROACH IN UAVS AND MEC ASSISTED NETWORKS: OUR CONTRIBUTION

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4.1 Introduction

In this chapter, we present our new Streaming Swarm Approach in UAVs and MEC assisted Networks (SSA-UMN) using a swarm of UAVs for improving the quality of experience in adaptive video streaming. Description the details of the proposed approach.

4.2 System Model

Usually the streaming videos are stored in servers and then delivered to end users via a network. In the proposed architecture, our server or source of information is indeed a swarm of UAVs that will capture and transmit the video in real time to the end-users via UAVs or vehicles, as we can use the 5th generation technology by integrating a MEC server with a base station to do the caching and transcoding, this last solution has been adopted and schematized in the figure 4.1.

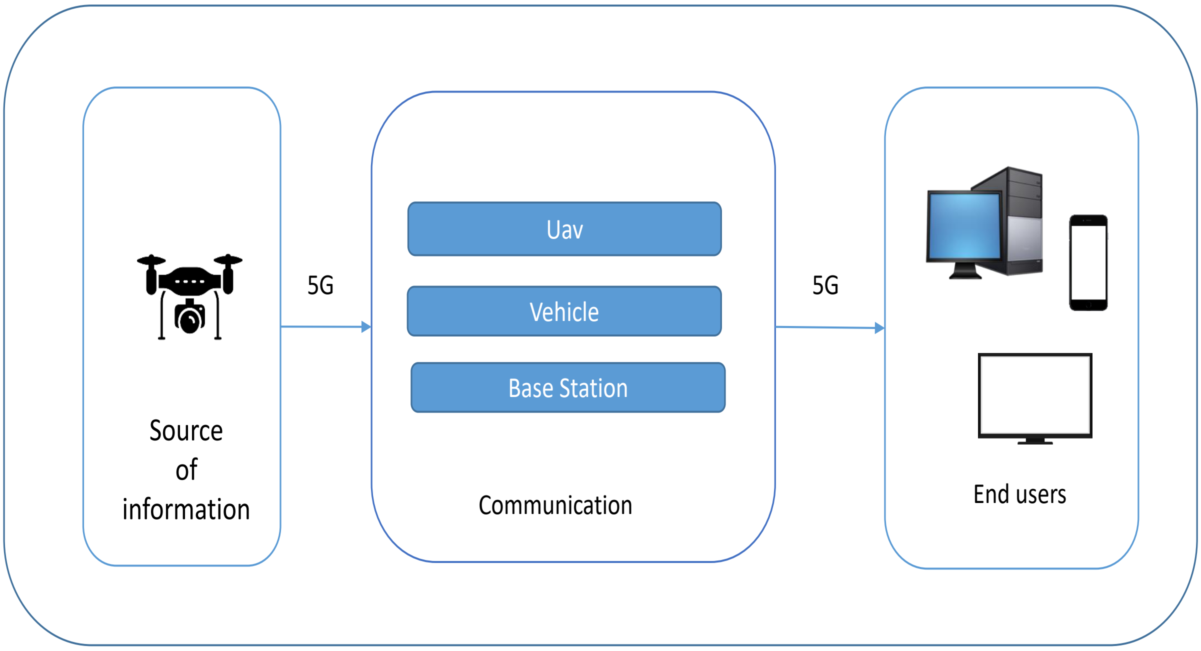

Figure 4.1: Streaming Architecture using UAV

4.2.1 Actors

- **Requester/Task initiator** could be any end user using a phone, personal computer, IoT device or an organization such as incident teams requesting to see the damaged places to allow rescue efforts to concentrate on areas of need.
- **Intermediate nodes** could be any device (BS, vehicle, UAV,..etc.) that forward the tasks to the end user and our provider.
- **Provider** which is a swarm of UAVs that streams the area of interest as shown in Figure 4.2.

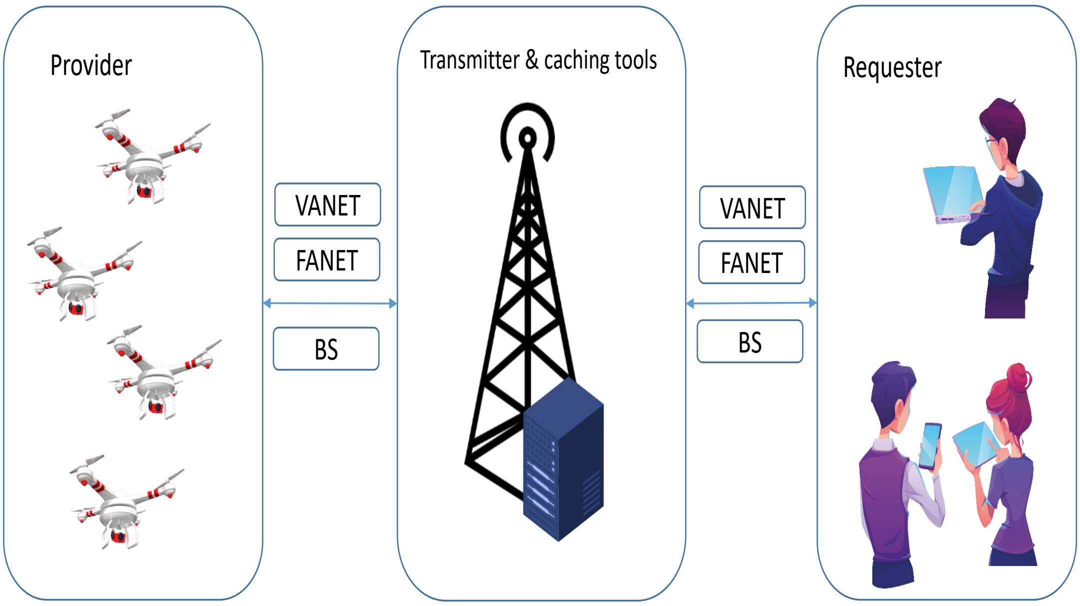

Figure 4.2: Solution Architecture

4.2.2 Overview of our protocol SSA-UMN

In this sub-section, We will be describing the method used by swarm of UAVs for streaming service. We assume that the UAVs are equipped with cameras and relevant equipment to the application. Algorithm 1 and Algorithm 2 present a formal description of the steps for the streaming process as below:

Algorithm 1: UAV Swarm streaming

```
Input: $StreamingTask$ ;
Output : Streaming service for $StreamingTask$ ;
Steps
1. Send $StreamingTask$ to the closest BaseStation ;
2. if ($Region_{Current}$ == Region) then
    2.a.1. Alert MEC to initiate $StreamingTask$ ;
    2.a.2. StartStreaming($StreamingTask$);
end
else
    while ($Region_{Current}$!== Region ) do
        2.b.1. Forward $StreamingTask$ to the next node;
    end
end
```

Algorithm 2: StartStreaming

```
Input: $StreamingTask(Region, StreamingTime, Altitude_{Avg})$ ;
Output : UAV token holder in Swarm Streaming for $StreamingTask$ ;
Steps
1. Alert UAVs to start streaming for $StreamingTask$ ;
2. for each $UAV \in N(UAV)$ do
    if ($Altitude_{Min} < Altitude_{UAV} < Altitude_{Max}$) And ($Busy_{UAV}$==False) then
        2.1. Send Reply to MEC server;
        2.2. MEC server adds $UAV$ to N($UAV_s$) ;
    end
end
3. MEC Server partitions StreamingTime into $StreamingInterval_j$ for $UAV_j \in N(UAV_s)$;
4. MEC server creates $Token$ ;
5. Send $Token$ to the closest $UAV_j \in N(UAV_s)$;
6. for each $UAV_j \in N(UAV_s)$ do
    while (Token== True) And ((CurrentTime-StartTime)<$StreamingInterval_j$) do
        6.1. $Busy_{UAV}$= True;
        6.2. Stream();
    end
    6.3. $Busy_{UAV}$= False;
    6.4. Forward Token to the next $UAV_s$ ;
end
```

The Streaming procedure of Algorithm 1 and Algorithm 2 can be summarized in the following steps:

(i) At first, an end-user demands streaming service and forwards the task request to the nearest base station as stated in step 1 of Algorithm 1.

(ii) As shown in step 2 of Algorithm 1, the base station either notifies the MEC server to initiate the streaming process or forwards to the task to the nearest node be sent to the targeted region of interest.

(iii) After delivering the task to the region of interest, the streaming process is initiated by the MEC server by alerting the UAVs in the region of interest as highlighted in step 1 of Algorithm 2.

(iv) Then, UAVs that are available and have the right altitude requirement reply the MEC server to start streaming as highlighted in step 2 of Algorithm 2 and its sub-steps.

(v) After replying to the MEC server, the MEC server partitions the total requested streaming time into time slots for each streaming UAV as shown in step 3 of Algorithm 2.

(vi) Next, the MEC server creates a token and forwards it to the closest UAV in the group of streaming UAVs as shown in steps 4 and 5 of Algorithm 2.

(vii) As demonstrated in step 6 of Algorithm 2 and its sub-steps, The UAV that owns the token starts streaming until the expiration of the associated stream interval of time. After finishing streaming, the UAV then forwards the token to the next streaming UAV.

The token is forwarded in the swarm of UAVs until the expiration of the requested total streaming time.

4.2.3 Example Scenario of SSA-UMN

To illustrate the functionality of SSA-UMN Algorithm, we consider a simple example presented in the Figure 4.3 which represents the scenario when a user requests a video stream while the requester is out of communication range of the base station. The request will be transmitted through intermediate nodes to the base station. Then the base station notifies the MEC server to initiate the streaming process by sending request to the UAVs.

4.3 Performance Evaluation

In this section, we present the simulation results that we have conducted to evaluate our protocol, while we used omnet++ as a simulator. We compare the performance of our streaming protocol using two routing protocols Ad-hoc On-demand Distance Vector (AODV) and Destination-Sequenced Distance Vector routing (DSDV) (SSA-UMNA, SSA-UMND). More details are in the following sub-sections.

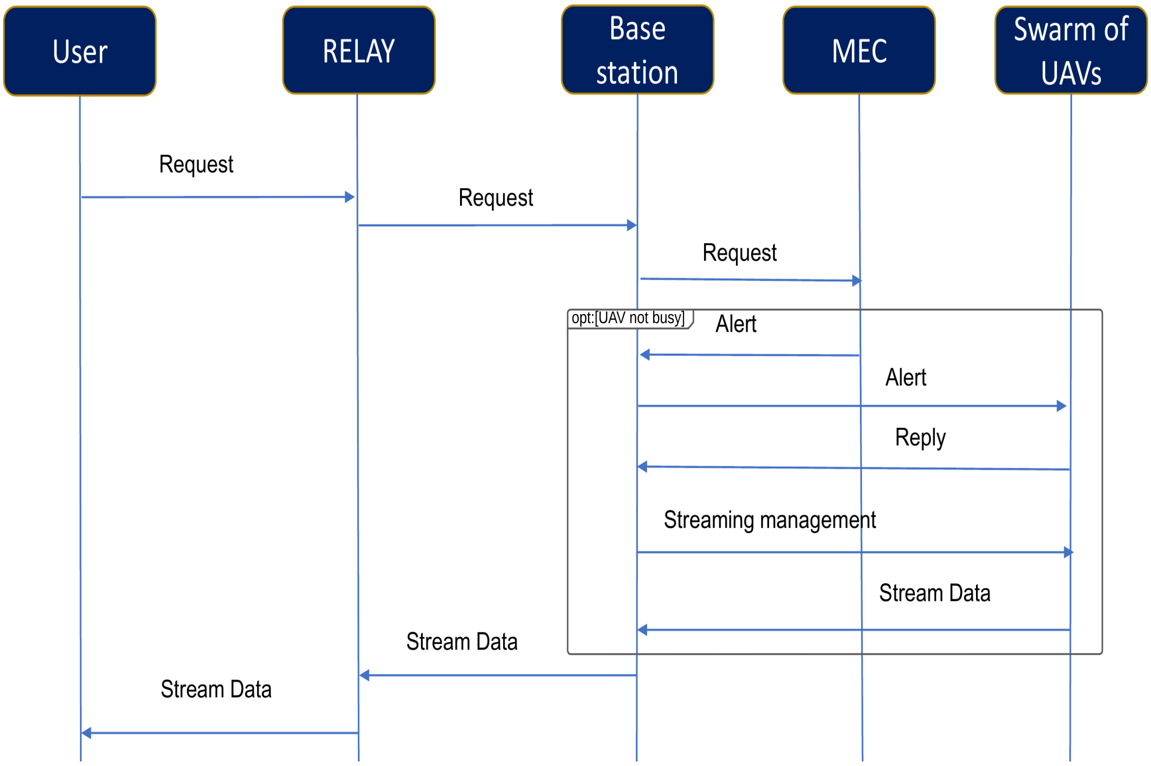

Figure 4.3: Example Scenario of SSA-UMN

4.3.1 Network Simulator

OMNeT++ stands for Objective Modular Network Tested in C++. It's a component-based simulation library written in C++ designed to simulate communication networks. OMNeT++ has eclipse based IDE and graphical runtime environment that makes it more attractive and easy to use.

We chose OMNeT++ to simulate our protocol because it is a realistic network simulator. Therefore, in our project different modules included UAV, BS can be added simulated and evaluated by the proposed system. In addition, mobility of UAV and relay nodes and its impact on the receiver can be easily managed, seen and evaluated.

4.3.1.1 Basic Parts of an OMNeT++ Model

An OMNeT++ model physically consists of the following parts:

- ***.Ned** language topology description(s) created by OMNeT ++, a software package used to create network simulation
- ***.anf** file contains the recorded simulation results (vector, scalar)

- ***.ini** file to initialize simulation parameters.

4.3.1.2 INET

INET Framework is an open-source model library for the OMNeT++ simulation environment. It provides a rich framework for mobile, wired and wireless networks.

4.3.2 Simulation Scenarios

To evaluate our proposal performances, we used the Omnet++ simulator through two scenarios. The performances are recorded taking Mass mobility model and increasing gradually drone density. The number of nodes ranges from 12 to 36 where are randomly deployed. The physical and MAC layer protocol used in this simulation is the CSMA/CA protocol. An area of 2000m x 2000m is used. The rest of two scenarios are described below:

1. In the first scenario, The speed of UAVs varies from 5m/s to 15m/s. We study the network performances while increasing gradually UAV density using AODV as a routing protocol. Simulation time is 600 seconds, while the the maximum transmission range of the nodes is set to 350 m.

2. In the second scenario, the parameters used are the same as the first one except that the routing protocol used is DSDV. Simulation parameters are summarized in Table 4.1.

Table 4.1: Simulation configurations

Parameter	1^{st} scenario	2^{nd} scenario
Mobility Model	Mass Mobility	Mass Mobility
Number of sources	1	3
Velocity	[5-15] m/s	[5-15] m/s
Simulated area	2000 m x 2000 m	2000 m x 2000 m
Number of total nodes	12,17,22,27	12,24,36,
Transmission range	350 m	350 m
Simulation time	600 seconds	600 seconds
MAC layer protocol	CSMA/CA	CSMA/CA
Packet size	100 bytes	100 bytes
Routing protocol	AODV/DSDV	AODV/DSDV

4.3.2.1 Simulation Analysis

To illustrate the results of our simulation, we selected the following performance metrics:

1. **End-to-End Delay** is the time taken to transfer a packet from its sending source to its receiving destination.
2. **Throughput** It is the total number of packets successfully transmitted divided by the simulation time. This parameter is calculated as the number of bits delivered per second.
3. **Jitter** is the time taken to transfer a packet from its sending source to its receiving destination.

Figure 4.4 shows the end-to-end delay performance while using one UAV as a video stream source. We observe that SSA-UMND significantly reduce the average delay in comparison of SSA-UMNA. The main reason for this results is that routing tables are periodically stored in SSA-UMND, and that prevents the long time in finding the best route even after modifications in the network topology.

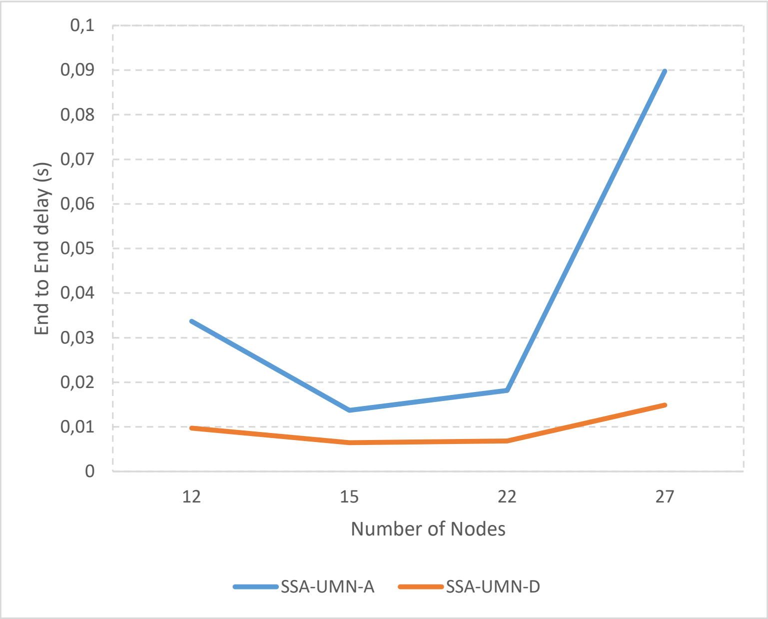

Figure 4.4: End-to-End delay Using one UAV as Video Source

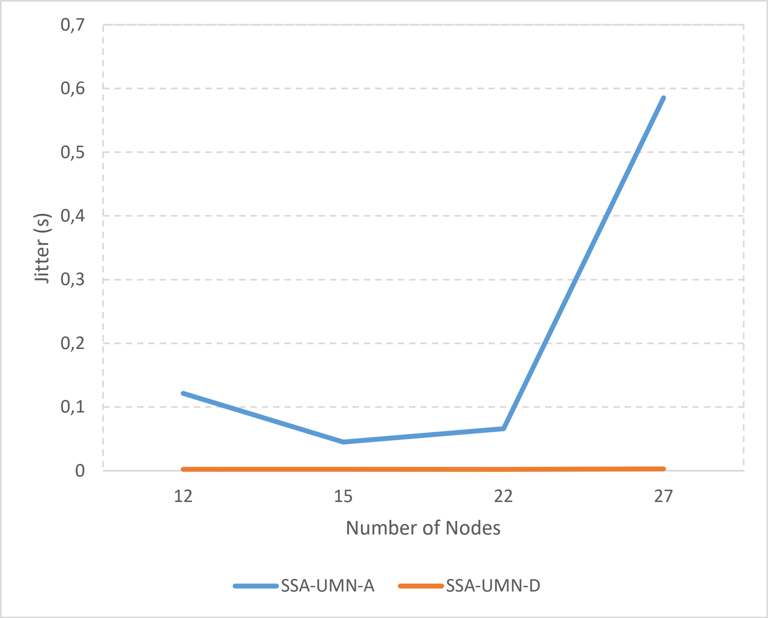

Figure 4.5: Jitter with 1 UAV as video stream source

Figure 4.5 represents the jitter of our solution using DSDV and AODV as a function of nodes density. The curves shows that SSA-UMND perform better than SSA-UMNA when it comes to jitter in our network. the increase of the jitter in the SSA-UMNA can be explained by the reconstruction of routes after a disconnection.

The utilization of throughput is presented in Figure 4.6, We observe that SSA-UMNA performs less when it comes to throughput compared to SSA-UMND protocol. The reason for that is the increased delay to reach destinations due to the discovery phase, while we notice a higher Throughput for SSA-UMND, but when the density of the network gets higher at the point when throughput is nearly 30000b/s SSA-UMNA starts to perform better than SSA-UMND.

Figures 4.7, 4.8, and 4.9 represent respectively the end-to-end delay, jitter and throughput in the network using 3 UAVs as streaming source.Results behave as same as the previous simulation results and that could be explained in it for the absence of collision in the network.

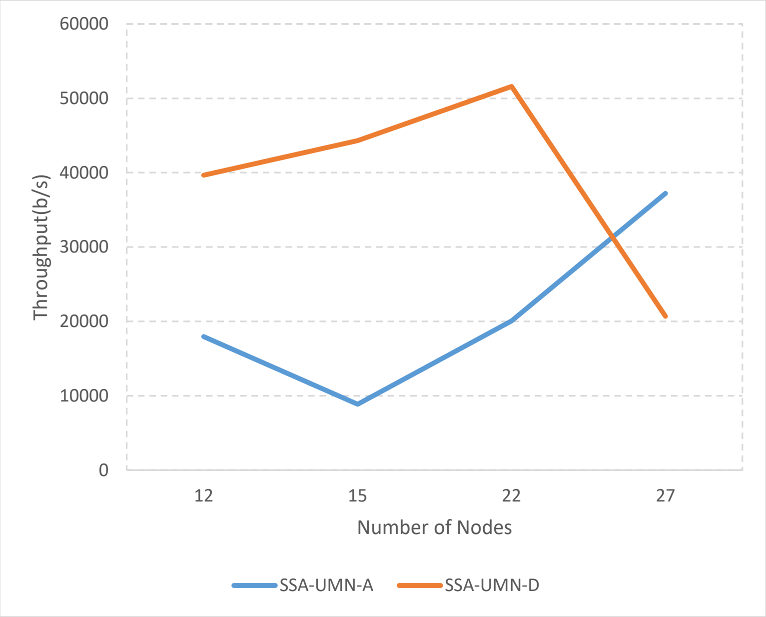

Figure 4.6: Throughput using 1 UAV as source

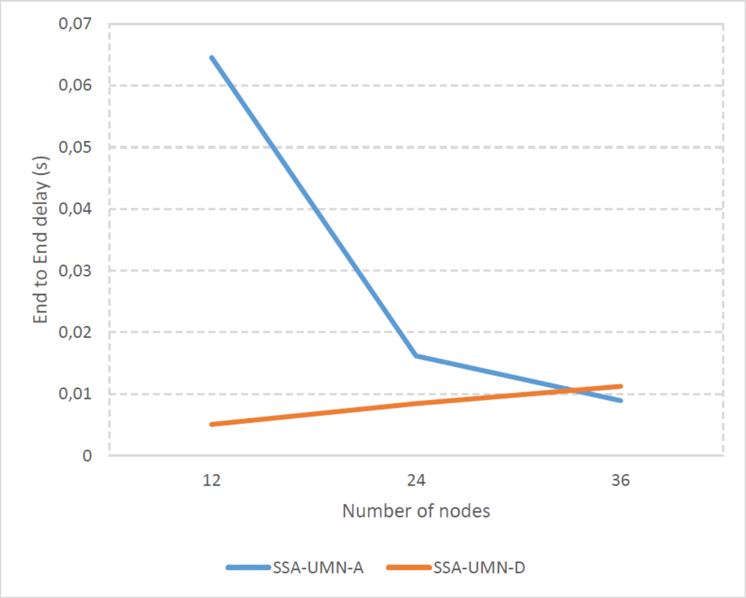

Figure 4.7: End-to-End Delay with 3 UAVs as Streaming source

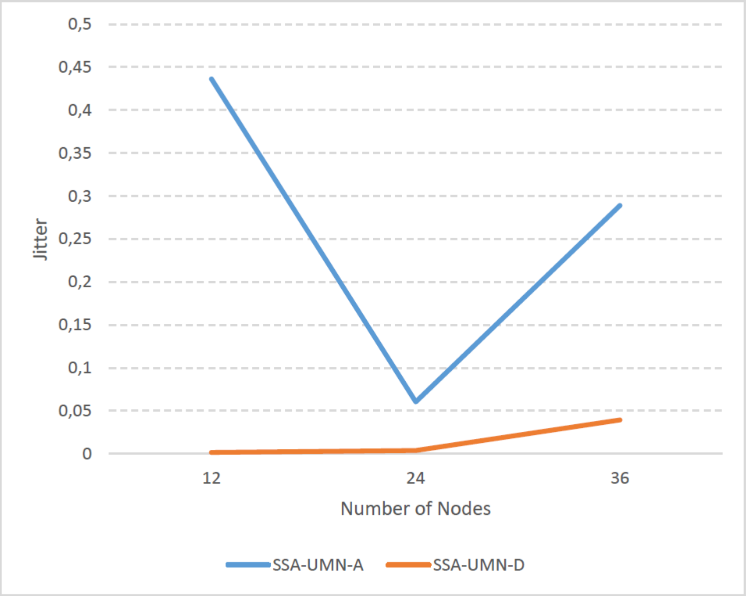

Figure 4.8: Jitter using 3 UAVs as Streaming source

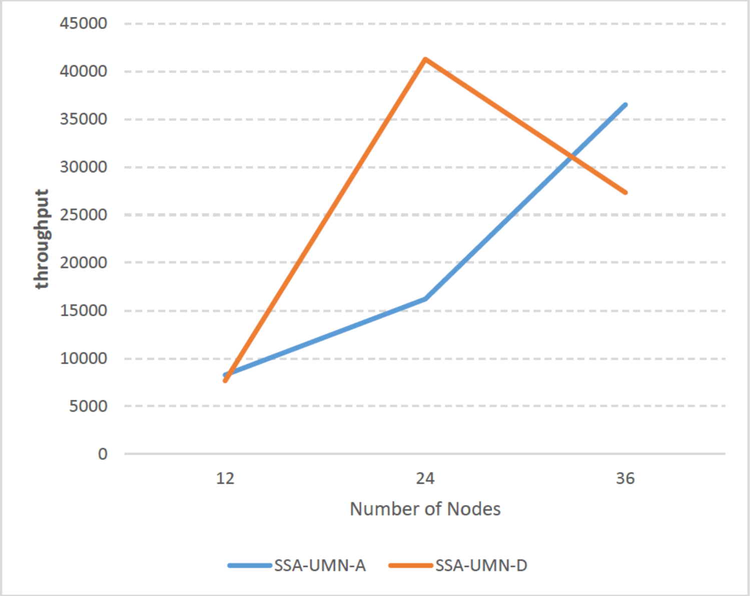

Figure 4.9: Throughput with 3 UAVs as Streaming source

Table 4.2: Simulation results for 10 sources

Parameter	AODV	DSDV
Number of sources	10	10
Total nodes	31	31
End-to-End Delay	0,03372(s)	0,006836 (s)
Jitter	0,23139(s)	0,00399(s)
Throughput	18109,22 (b/s)	41825,31 (b/s)

Table 4.2 presents the simulation results for 10 sources, where it is figured that the end to end delay of SSA-UMNA is larger then the SSA-UMND which implies that the jitter is also lagrer in the SSA-UMND, with the throughput of AODV less than DSDV which confirmed our simulation results.

Finally, we believe that SSA-UMND is not adapted for large networks, but in small networks it gives higher performance which is proved in the simulation results.

4.4 Conclusion

In this chapter, we presented our streaming routing protocol for a swarm of UAVs and discussed its performance and effectiveness through Omnet++ simulator.

CHAPTER 5

CONCLUSION AND FUTURE PERSPECTIVES

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5.1 Summary of our Work

More recently, MEC and swarm of UAVs are growing in importance and play an essential role in a wide range of applications and complex missions in several domains. Indeed, streaming routing plays a crucial role in ensuring the right functionality and efficient co-operative network operations. In this work, we have presented a new streaming routing protocol. As a first step, we have introduced UAVs and discussed their types. We have also presented an overview of swarm-based systems and their main architecture and discussed the architecture of the MEC, and presented the main streaming applications in UAVs. As a second step, a brief state-of-the-art of the existing streaming routing protocols in swarm of UAVs is undertaken. As a third step, we have presented our streaming method in a swarm of UAVs. It is based on streaming using a token where every UAV streams in a slot-time.

5.2 Future Perspectives

To build on the work accomplishments, some future perspectives should be considered to design new streaming swarm approaches. One of the future work directions is to compare our solution with other routing protocols that would provide more realistic comparative results with other protocols. Another direction for extending our solution by adding security mechanisms and adapting more scalable networks.

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