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SUBMITTED BY: Sara Yassmine Brahimi & Fatna Mouffak

THEME

Selection of Cloud Services in MEC and UAV enabled Networks

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MÉMOIRE DE MASTER

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THÈME

Sélection de services de Cloud dans les réseaux de drones

Soutenu publiquement devant le jury composé de :

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Fatna & Sara, June 2022

Dedications

*I dedicate this work to my dear parents (**Mouffok Houcine and Lamri Samia**), for their patience, love, support and encouragement for me to do better.*

My dear brother Mouhamed and my sisters Khadidja and Meriem your support has been a pride for me throughout my academic career, to my whole family.

*Also I dedicate this work to the spirit of my nanny and dear grandmother to my heart, **El hadja Mebarka Ben Jalloul**, may Allah have mercy on her pure spirit.*

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Dedications

These are the feelings I have for those who have given so much And who have always been there for me, and who supported me in the most difficult times, my very dear parents ***Lazhari Brahimi*** *and* ***Fatima Outhmani*** *may Allah keep them. I dedicate this modest work to them.*
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To my Master2 classmates in general.

Thanks everyone.

Sara Yasmine Brahimi

Abstract

Nowadays, Mobile Edge Computing (MEC) and Unmanned Aerial Vehicle (UAV) clouds attract a lot of attention of both academic and industrial research as a new paradigm providing flexible and elastic services. This paradigm utilizes the recent technologies of Mobile Cloud Computing (MCC) and Internet of things (IoT). The collaboration between these new technologies represents an impressive vision of the future, in which everything is connected to the Internet, using Fifth Generation (5G) technology that integrate the MEC server, which can provide instant computing applications with low latency and fast service response. In this work, the new cloud computing with MEC and UAV technology is studied, our main objectives are to (i) provide detailed classification of existing selection of services methods in UAV clouds and to (ii) propose a new technique Game Theory approach for Cloud Services in MEC and UAVs enabled networks (GTCS-MU) aiming to enable normal end user that he set a group of specific features, limitations and prices selecting the most suitable UAV-Service-Provider. Given that every service' provider is characterized by specific features, limitations and prices, a user must select the most suitable provider. The technique of selection will be based on Game Theory (GT) and takes into account the user requirements and the UAV provider qualities to find the most adequate provider. The results of the simulation conducted using OMNet++ simulator and Inet framework advocate for the efficiency and the good performance of our method that present in low latency at most 0.45s between the two scenarios, high successful execution ration that reach 100% with 50 Unmanned Aerial Vehicles (UAVs) and good management of energy consumption that could be in worst case 14.5% of lost.

Keywords : **UAVs, MEC, Selection of Services, IoT, Game Theory, GTCS-MU.**

ملخص

في الوقت الحاضر، جذبت الحوسبة المتنقلة وسحابة الطائرات بدون طيار الكثير من الإهتمام لدى البحوث الأكاديمية والصناعية كنموذج جديد يوفر خدمات مرنة. يستخدم هذا النموذج التقنيات الحديثة للحوسبة السحابية المتنقلة وأنترنت الأشياء. يمثل التعاون بين هذه التقنيات الجديدة رؤية واعدة للمستقبل، حيث يتم توصيل كل شيء بالإنترنت بإستخدام تقنية الجيل الخامس التي تدمج خادم الحوسبة السحابية المتنقلة الذي يمكن أن يوفر تطبيقات الحوسبة الفورية مع زمن انتقال منخفض واستجابة سريعة للخدمة. في هذا العمل، ندرس الحوسبة السحابية الجديدة مع تقنيات الحوسبة السحابية المتنقلة وإنترنت الأشياء، تتمثل أهدافنا الرئيسية في (1) تقديم تصنيف مفصل لطرق إختيار الخدمات في سحابة الطائرات بدون طيار و (2) إقتراح تقنية جديدة (GTCS-MU) تهدف إلى تمكين المستخدم العادي من تعيين مجموعة من الميزات والقيود و الأسعار المحددة لإختيار أنسب مزود خدمة الطائرات بدون طيار. نظرا لأن كل مقدم خدمة يتميز بميزات وقيود وأسعار محددة، يجب على المستخدم إختيار أنسب مزود. تعتمد تقنية الإختيار على نظرية اللعبة وتأخذ بعين الإعتبار متطلبات المستخدم وخصائص مزود الطائرات بدون طيار للعثور على المزود الأكثر ملاءمة. أثبتت نتائج المحاكاة التي أجريت بإستخدام المحاكي ++OMNET و INET كفاءة أداء طريقتنا.

الكلمات المفتاحية :الطائرات بدون طيار، الحوسبة السحابية المتنقلة، إختيار الخدمات، إنترنت الأشياء، نظرية اللعبة، GTCS-MU.

Résumé

De nos jours, le cloud véhiculaire aérien sans pilote de drone (UAVs) et de serveurs (MEC) a attiré une large attention de la communauté de la recherche académique et industrielle en tant que nouveau paradigme fournissant des services flexibles et élastiques. Ce paradigme utilise les technologies récentes de MCC et IoT. La collaboration entre ces nouvelles technologies représente une vision impressionnante de l'avenir, dans laquelle tout est connecté à Internet à l'aide de la technologie 5G qui intègre le serveur MEC qui peut fournir des applications informatiques instantanées avec une faible latence. Dans ce travail, le nouveau cloud avec les technologies MEC et IoT sera étudié, nos principaux objectifs sont de (i) présenter une classification détaillée des méthodes existantes de la sélection des services et de (ii) proposer une nouvelle technique (GTCS-MU) visant à permettre à l'utilisateur final de définir un ensemble de fonctionnalités, de limitations et de prix spécifiques en sélectionnant le fournisseur le plus approprié. Étant donné que chaque fournisseur de service est caractérisé par des caractéristiques, des limites et des prix spécifiques, un utilisateur doit sélectionner le fournisseur le plus approprié. La technique de sélection est basée sur la méthode de théorie des jeux (GT) et prendra en compte les exigences de l'utilisateur et les qualités du fournisseur de drones afin de trouver le fournisseur le plus adéquat. Les résultats de la simulation réalisées à l'aide du simulateur OMNeT++ et du framework INET montrent l'efficacité et les bonnes performances de notre méthode, cela présente en faible latence (au maximum 0.45s entre les deux scénarios), un taux d'exécution réussi élevé qui atteint 100% avec 50 UAVs et une bonne gestion de la consommation d'énergie qui pourrait être dans le pire des cas 14.5% de perte.

Mots clés: : **UAVs, MEC, Sélection de Services, IoT, Théorie des Jeux, GTCS-MU**

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List of Acronyms

3G Third Generation. 30, 31

4G Fourth Generation. 8

5G Fifth Generation. v, i, iv, 1, 8, 14, 15, 16, 17, 18

AI Artificial Intelligence. 28

AODV Ad Hoc On-Demand Distance Vector. 45

BiC Bio-inspired Computing. 29

BS Base Station. 25, 26, 31, 38, 39

CC Cloud Computing. 1, 2, 3, 9, 11, 18, 19, 49

CG Cooperative Game. 22

EC Edge Computing. 2, 3, 11, 12, 19, 49

ES Edge Server. 30, 31

FLC Fuzzy Logic Controllers. 20, 21

GA Genetic algorithms. 20, 21, 26, 29

GBS Ground Base Station. 4, 7, 8, 9, 30

GT Game Theory. v, i, iv, v, 2, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 32, 34, 35, 37, 42

GTCS-MU Game Theory approach for Cloud Services in MEC and UAVs enabled networks. v, iii, iv, 2, 34, 35, 36, 37, 41, 42, 43, 48, 49

IoT Internet of things. v, i, 3, 11, 12, 13, 16, 18

LoS Line-of-Sight. 7, 8

LTE Long Term Evolution. 15, 30

MALE Meduim Altitude Long Endurance. 25

MANET Mobile Ad-hoc NETworks. 2, 21, 29

MCC Mobile Cloud Computing. v, i, iv, v, 10, 11, 13, 14, 18

MEC Mobile Edge Computing. v, i, iii, iv, v, 1, 2, 13, 14, 16, 17, 18, 32, 36, 37, 39, 40, 41, 42, 44, 45, 48, 49

N-CG Non-Cooperative Game. 22, 24, 26, 29

NE Nash Equilibrium. 32

NIST National Institute of Standards and Technology. 9

NR New Radio. 15

PSO Particle Swarm Optimization. 20, 21

QoE Quality of Experience. 8, 9, 37

QoS Quality of Service. 8, 20, 27, 32, 34, 35, 36, 37, 41

R Requester. v, 32, 37

RPA Remotly Piloted Aircraft. 4

RPAS Remotly Piloted Aircraft System. 4

RPT Robot Path Planing. 28

RPVS Remotely Piloted Vehicle System. 4

RRT Rapidly-exploring Random Tree. 28

SATCOM Satellite Communication. 7, 8, 27

U-WCN UAV Wireless Communication Networks. 20, 21, 23

U2G UAV-to-Ground. 7, 27

U2U UAV-to-UAV. 7, 27

UAS Unmanned Aerial System. iv, 4, 5, 9, 23

UAV Unmanned Aerial Vehicle. v, iii, iv, v, 1, 2, 4, 5, 6, 7, 8, 9, 15, 18, 19, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 42, 44, 45, 46, 48, 49

UAVs Unmanned Aerial Vehicles. v, i, iv, 1, 2, 3, 4, 5, 7, 8, 10, 13, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30, 32, 37, 39, 41, 44, 45, 46, 49

VANET Vehicular Ad-hoc NETworks. 2, 21

VTOL Vertical Takeoff and Landing. 5

WLAN Wireless Local Area Network. 31

1 Introduction

Contents

1.1 Context

During the last decade, users can access a variety of services and applications thanks to technological advancements in wireless communication and the growing use of Cloud Computing (CC). Furthermore, with the new technology of UAVs and due to their autonomy, flexibility, and broad range of application domains. UAVs have been widely deployed and adopted in a variety of fields, such as military missions (e.g., monitoring and control), civilian uses (e.g., delivery and photography), rescue operations (e.g., disaster relief, and medical suppliers), and many other tasks [9, 10, 11, 12, 13].

UAVs services are inherently critical, and they necessitate a reliable, low-latency control link with the drones during services. To ensure low-latency, 5G architecture intends to deploy MEC servers, which provide CC capabilities close to the end-users. MEC has been identified as a promising solution for addressing this problem, and it is attracting more study attention from industry and academia [14]. In addition, UAVs integrated with MEC will play a critical role by introducing an additional mobility based computational layer to provide more secure, efficient and faster services [15]. However, this desirable partnership poses a lot of challenges in selecting the most suitable service such as, time and energy consumption required to execute the task.

1.2 Problem Statement and Motivations

Beside the fast evolution of UAV clouds and their efficient services they provide any time and any where to the users, more difficulties are come out then ever basically in how build a communication stand between the consumer and the provider add to that select the best service with the existing of a set of features, limitations and price for each side. Moreover, the research and development of selection of cloud services in MEC and UAVs enabled networks is currently in its early stages, with only a few studies conducted in this direction. On the other hand, in the research literature, many service selection methods are proposed in Mobile Ad-hoc NETworks (MANET) [16, 17] and Vehicular Ad-hoc NETworks (VANET) [18, 19, 20]. However, only a few works can be found in the related literature addressing the selection of services in UAV clouds [8] [21]. In [8], authors proposed a new approach for Services' Selection in UAVs Clouds aiming to enable normal users to select the most suitable UAV-Service-Provider. However, in this solution, the energy consumption is not considered, that is what motivated us to propose a new solution for selection of cloud services in MEC and UAVs enabled networks, that can play the role of mediator to help each side (Consumer & provider) to get satisfied, by maximizing the payoff to each of them.

1.3 Organization of the Memoire

This memoire is organized as follows:

- In **Chapter 2**, we provide an overview of Unmanned Aerial Vehicles (UAVs), Cloud Computing (CC), and Edge Computing (EC).
- In **Chapter 3**, we illustrate some related methods of services' selection with a brief showing to their advantages and drawbacks and with a detailed synthesis and comparison.
- In **Chapter 4**, we present our new method (GTCS-MU). First, we start by giving an overview of Game Theory (GT), then we describe our method's implementation along with giving an example to further clarify it's steps.
- Finally, we finish by giving a general conclusion summarizing this work and the possible routes that we could take in furthering its development in the future.

2

Unmanned Aerial Vehicles, Cloud Computing, and Edge Computing: Background

Contents

2.1 Introduction

In the past few years, unmanned aerial vehicles (UAVs) have been extensively increasing and widely applied in diverse IoT applications including real-time monitoring, remote sensing, search and rescue, delivery of goods, security and surveillance, and precision agriculture. More recently, the integration of EC technology into UAV-assisted networks has attracted great attention that extends CC services closer to data sources, which can significantly improve the computation capacity and reduce the latency and bandwidth cost.

Along this chapter, we start with the an overview of UAVs, their classifications, applications and their communication architectures, in addition to that we present some challenges that face it. Then we present the background of both CC and EC.

2.2 Unmanned Aerial Vehicles

Unmanned aerial vehicle UAV, commonly known as Remotly Piloted Aircraft (RPA) or drone, is a pilotless aircraft that does not require any direct human intervention for flying, is powered by a jet or reciprocating engine, and can navigate autonomously according to a pre-programmed flight plans or can be controlled remotely [22] [9]. To improve the performance of UAVs on their missions, researches are conducted to make UAVs cooperative in a controlled way autonomously or by a control station.

2.2.1 Unmanned Aircraft System

Unmanned aircraft system also called as UAV System, Remotly Piloted Aircraft System (RPAS), or Remotely Piloted Vehicle System (RPVS). It includes elements such as UAVs, Ground Base Station (GBS), radio controller, equipment and systems necessary during the flight operation as shown in Figure 2.1.

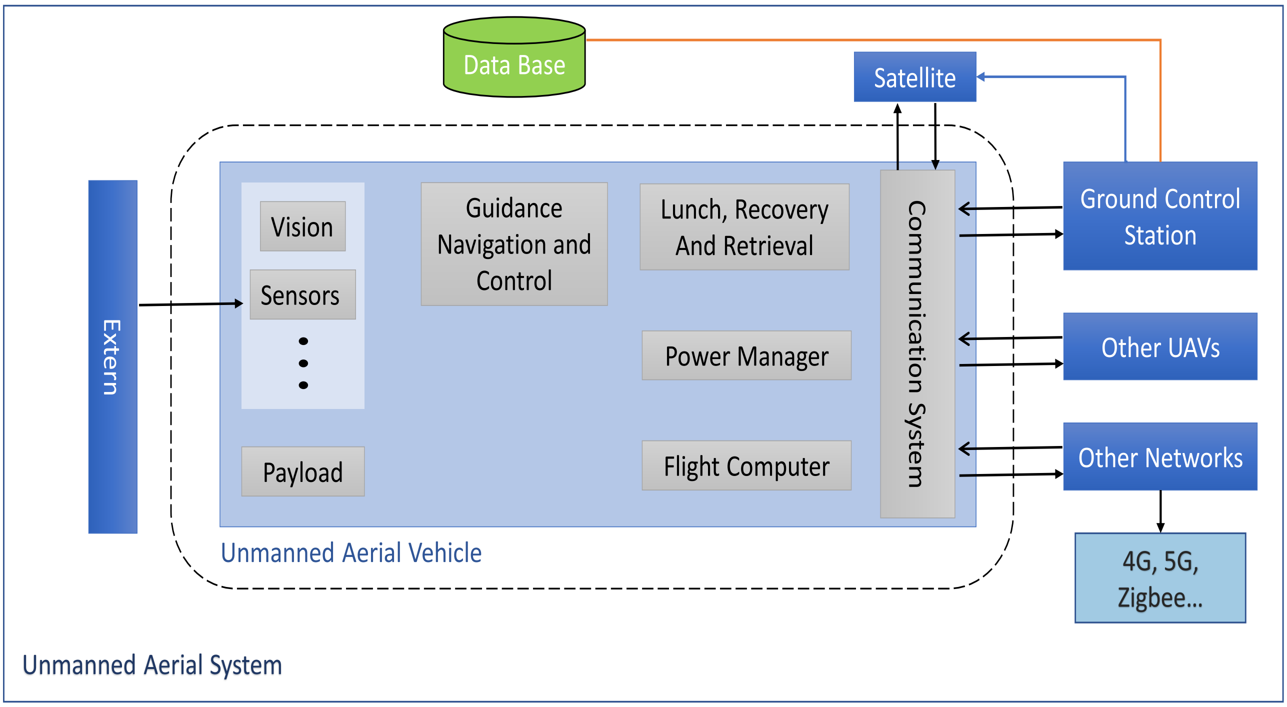


Figure 2.1: UAS Architecture [1]

2.2.2 Classification

According to the studies in [9, 6], UAVs can be classified based on different characteristics such as, body style, weight, range, altitude, and endurance.

1. **UAV Body Style :** UAVs can have many different body styles or shapes depending on the flight style and intended usage or missions. UAV body styles mainly classified into one of the following types [9]:

- Fixed-Wing : Are modeled after conventional airplanes and utilize the same flying concepts.
- Multi rotor : Multirotor UAV can be configured using multiple motors installed on arms. This body type has the advantages of vertical takeoff and landing and can hover in a fixed position.
- Vertical Takeoff and Landing (VTOL) : Is very versatile as it can be a hybrid of the two previously mentioned body styles (i.e., fixed-wing and multirotor).

2. **Weight :** Based on their weight, UAVs can be classified into nine (9) categories as shown in table 2.1.

Table 2.1: UAV Classification based on Weight [6].

Class	Maximum Weight	Maximum Range
Nano	200g	5km
Micro	2kg	25km
Mini	20kg	40km
Light	50kg	70km
Small	150kg	150km
MALE	1000km	200km
HALE	1000km	250km
Heavy	2000kg	1000km
Super Heavy	24,950kg	1500km

3. **Range, Endurance, and Altitude :** UAV can be classified with another important metric witch is the endurance, it does mean how long a UAV can fly in term of time, its value can change from 1 hour to 36 hours. Another parameter can be used in UAV classification is the range, which describe how far a UAV can fly away from its ground control station. Authors of [6] classified UAVs into six (6) categories (Table 2.2).

Table 2.2: UAV Classification based on range and endurance [6].

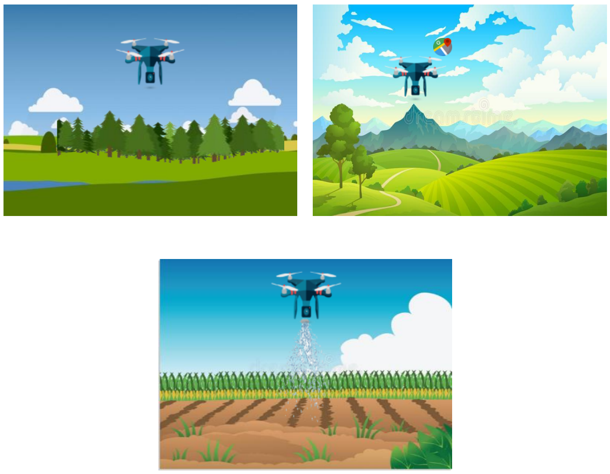
Category	Maximum Range	Maximum Endurance
Very Close Range	5km	$\prec$ 6h
Tethered UAS	50km	6h
Close Range	150km	12h
Short Range	2Kg	1m
Mid-Range	650km	12–36h
Endurance	300km	36h

In addition, UAV can be classified into three (3) classes according to their maximum altitude [6]:

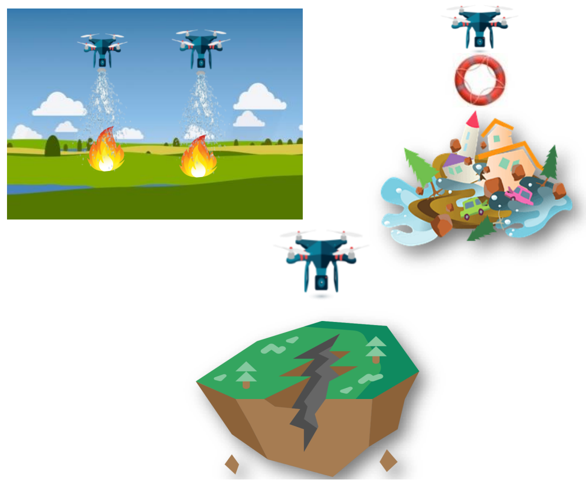
- Low altitude: Less than 1000 m.
- Medium altitude: Between 1000 m and 10,000 m.
- High altitude: More than 10,000 m.

2.2.3 Applications

UAV can use in many fields due to the development of their technologies. In addition, they can be deployed in different applications including military and civil applications due to their low maintenance cost, high mobility, and their ability to stay airborne (c.f. Figure 2.2).



(a) Precision Agriculture.



(b) Search and Rescue.

(c) Delivery.

Figure 2.2: UAV Applications.

1. **Precision Agriculture :** UAV was an important element most used in agriculture to execute various tasks that including crop management, weed/disease detection, pesticide spraying, and irrigation. They are many advantages to using UAV for agriculture application such as low cost and reducing delay compared to the traditional ways of agriculture. UAVs allow farmers to gather information about their plants to take idea about the best kind of fertilizers adopting with his crops (Figure 2.2a).

2. **Search and Rescue :** Search and rescue operation is one of the important event for optimizing human risk into a rescue situation due to the scope of disasters. They can help by using a recovery operation and use emergency equipment after disasters like earthquakes, floods, capsized boat, and drawing. In this case is recommended to use a swarm of UAVs that include sensors and cameras. In addition, UAV can be able to take a high resolution of image and best quality of video to check a real time photo for each disaster (Figure 2.2b).

3. **Delivery :** UAVs have the ability to deliver packages to a specific geographic area. Recently, more companies like Amazon have been interested by this type of drones to transport services to their customers such as food delivery of package and equipments necessary for medicine (Figure 2.2c).

2.2.4 Communication Architectures

Each node in the network (i.e., UAV, GBS, and Satellites) can act as an end system. However, the communication of two distant nodes is exposed to different constraints, such as sudden disconnections, packet loss, and the permanent fragmentation of the network. Therefore, all these nodes can cooperate and organize themselves as relays in order to cope well with the frequent topology variation. Thus, this arises four types of communication: (i) UAV-to-UAV UAV-to-UAV (U2U), (ii) UAV-to-Ground (U2G), (iii) Satellite Communication (SATCOM), and (iv) UAV-to-Cellular Network [9], as shown in Figure 2.3.

1. **UAV-to-UAV Communication**: To satisfy the needs of different missions, UAVs directly communicate by frequently exchanging data packets with each other. However, due to the restrictions on the transmission ranges, multi-hop communication is carried out over other UAVs. This is crucial to extend the coverage of a specific area of interest. In the majority of cases, the Line-of-Sight (LoS) is predominant in U2U communications since no obstructions exist between UAVs in the sky. Nevertheless, there are exceptional cases where LoS is not guaranteed, especially when UAVs are exposed to high rise buildings or mountains.

2. **UAV-to-Ground Communication**: For a better control of flying UAVs, infrastructures in the form of GBSs are fixed on the ground in order to exchange critical control and command messages. In addition, GBSs are also used to link different groups of UAVs between each other. Generally, there are specific UAVs that are able to communicate with GBSs in order to decrease the congestion of the network and to enhance throughput and connectivity. If UAVs fly at high altitudes, the LoS is predominant in U2G links. However, at low altitudes, UAVs do not ensure an LoS with GBSs due to the existing obstructions on the ground causing reflection and diffraction phenomenons.

3. **Satellite Communication**: UAVs are often deployed in complex environments, where it is difficult to install GBSs or when a group of UAVs requires continuous connectivity and the network is severely partitioned. For this purpose, there is a need for a centralized entity ensuring permanent connectivity like using satellites as an adequate option to serve as relays controlling UAVs in a centralized manner and also providing an important LoS coverage, thus establishing Satellite Communication (SATCOM).

4. **UAV-to-Cellular Network:** In recent years the evolution of cellular network has been the talk show of all communication technology research, from voice communication to multi-type data (Voice,Text, Image & Videos) exchange, specially when 5G came out with all it great benefits that's what create space of interaction between UAVs and Fourth Generation (4G) & 5G technology which is very helpful for a simple user of UAV.

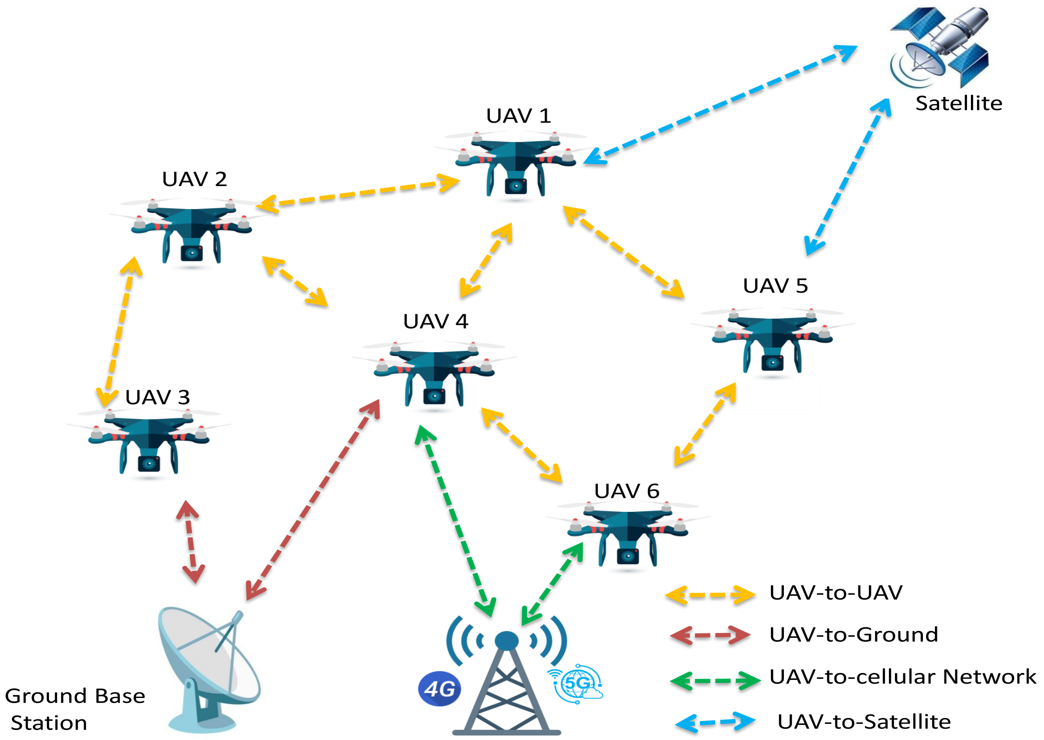


Figure 2.3: UAVs communications.

2.2.5 Challenges

As the technology of UAVs grows and evolves further, their applications in the UAV Clouds to do tasks for users anytime and anywhere is adopted on an increasingly wider scale, new challenges are now more present than ever, such as delay, collision avoidance, energy consumption, security, and Quality of Experience (QoE).

1. **Delay :** Some of the tasks need to be execute in a high throughput and with a perfect Quality of Service (QoS) like video streaming also with a minimal delay, we need to select the best task that take a least delay between the moment of sending the request and the moment of receiving data.

2. **Collision Avoidance :** In the operation of flight, it is possible to avoid accident by crashing UAV with any obstacle (fixed or mobile). To detect it should recommended to use UAV mounted with a camera with a high quality to take a real time images to avoid the collision challenge.

3. **Energy Consumption :** The energy capacity of a UAV is considered to be a essential factor. UAV can have many operations which consume energy due to the mobility in the 3D space.

4. **Security :** The security of the UAV is an important components in UAV, when the communication in UAS is required to collect and share data to another device (UAS, GBS, and Satellite). So will be must to assuring confidentiality and integrity information during this connection because it possible that other source may be attempt to attacked.

5. **Quality of Experience :** Is a metric of the general level of requester satisfaction with a service provider, which a value that the service provider takes from the requester expressing his opinion and his conviction of service provider to him. The best QoE evaluation is obtained by a maximum number of requesters. In addition, the major factors that influence in the value of QoE include cost, privacy, and security.

2.3 Cloud Computing

Many definitions set to introduce the Cloud Computing (CC), we take as example the qualifier of the National Institute of Standards and Technology (NIST) that define the CC as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [23].

As well CC can be defined as a group of investors (service providers) whose set a group of resources (servers, routers, storage, application, ...etc.) to can easily accessed and used virtually by a mount of consumers (peoples, IoT, ...etc.) on demand with a cheap cost comparing to the great services they provide and high performance of computing (Figure 2.4).

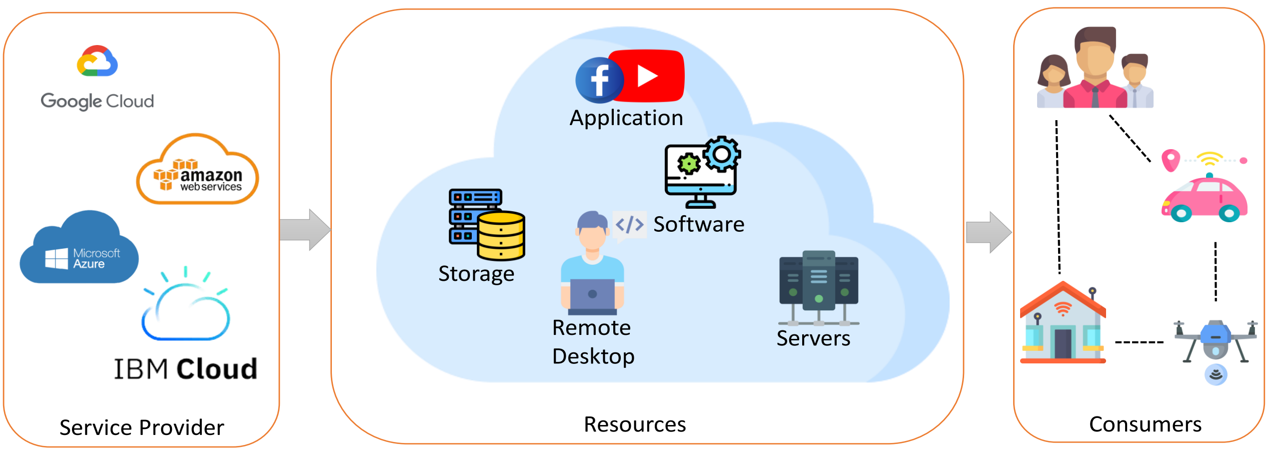


Figure 2.4: Cloud Computing Architecture

2.3.1 Cloud Computing Service Models

1. **Infrastructure as a Service :** IaaS it represent the use of physique devices as a service like processors, storage servers, network devices and more but on distance with a define price. It used more by companies and administrators because for them it saves budget in cross of it great service. On of the most providers of this service is Amazon, Microsoft and Google cloud [24].

2. **Platform as a Service :** PaaS this service is designed for the developers when they use it as computing and development tools platform to facilitate the process of creating a software faraway from their infrastructure layer. It include Operating systems, Web tools and programming languages. The PaaS leaders are Amazon web services, Microsoft Azure and Google cloud [24].

3. **Software as a Service :** SaaS this layer is designed for simple users which provide an access to a different applications and software that suffers from paying it license upfront fee, they benefit just from monthly or annually fee to subscribe to it. SaaS users can access to the service from any device that is connected to the internet any where and any time. the most famous example is Facebook, Microsoft Office 365 and Adobe Creative Cloud [24]. All the models are show in the Figure 2.5.

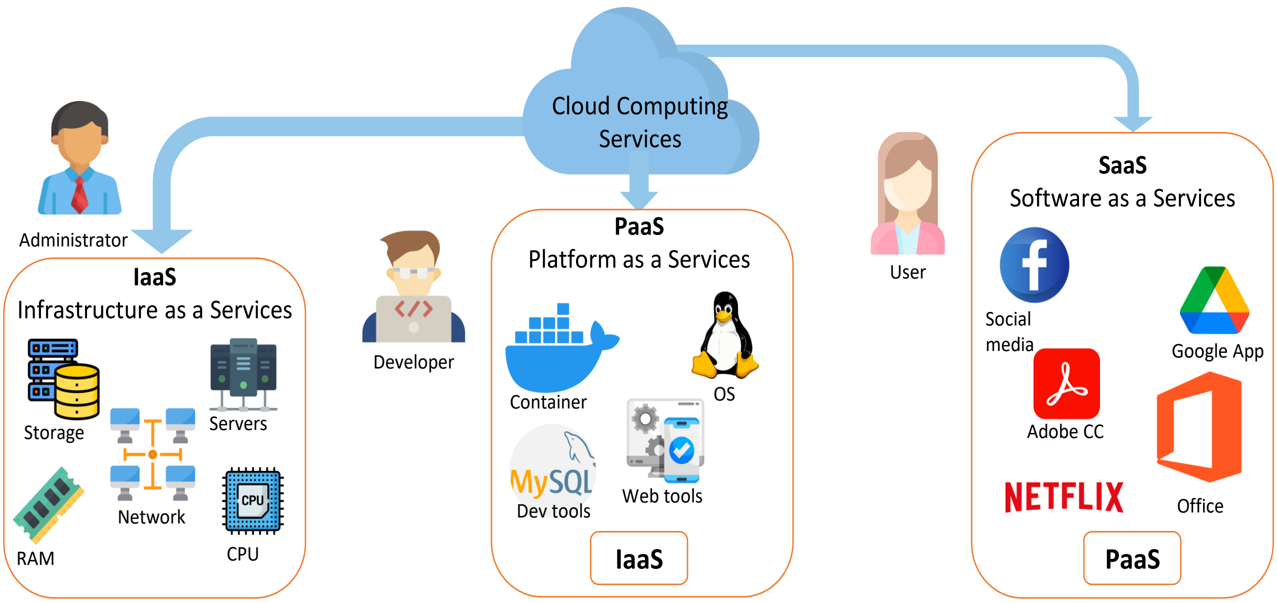


Figure 2.5: Cloud Services

2.3.2 Mobile Cloud Computing

Mobile Cloud Computing (MCC) is the integrate of mobile devices such as (vehicles, UAVs,...etc.) and cloud computing services, to improve mobile devices capabilities such as storage and computing. It can interact with the cloud via a web services which act as Application Programming Interface (API) through a near base station. MCC despite of the power of cloud except that the main limitation of the MCC is the long transmission distance between the mobile device and the cloud, which create a problem for sensitive delay application [2]. The architecture of MCC is presented in Figure 2.6.

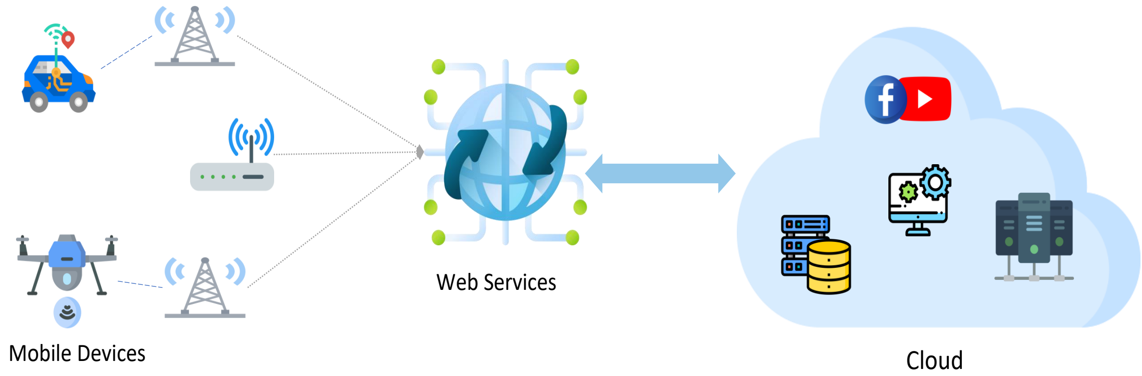


Figure 2.6: Mobile Cloud Computing Architecture [2]

2.4 Edge Computing

Edge Computing (EC) is a term who have a direct relationship to the CC which consider as a distributed architecture of CC to bring closer the ability of storage and computing to the device or the person who use data, this term was born with the appearance of IoT.
In simple definition of edge computing is a powerful local[1] computing and storage, that's mean it is not necessary any more to pass a long distance to reach a data center to accomplish the task. The main purpose is to closer the data and the computing to the user. It is great solution for the latency sensitive applications (Figure 2.7).

[1]On the edge of the networks like base stations, routers and gateways

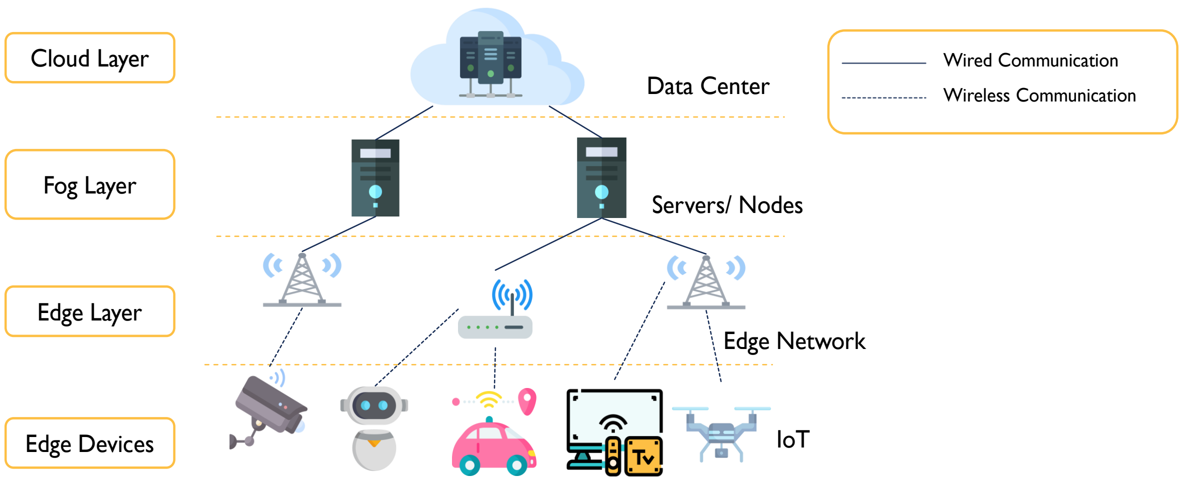


Figure 2.7: Edge Computing Architecture

As the Figure 2.7 shown the EC consist a multi layers, the fog layer which group of servers link the data center with the edge layer that form the network layer (base station, routers,...etc.). The meaning of edge is more clear in edges devices layer, where this last one introduce the IoT layer that is faraway from the cloud layer, here the effect of EC will show on when every device benefit from each other capability.

2.4.1 Internet of Things

Internet of Things (IoT) is a concept that has emerged over the last years that lead to EC concept to show up, it is a group of devices (smart phones, tablets, PCs, routers, servers,...etc.), vehicles, a house equipment, sensors (Figure 2.8) or any thing can send or receive data, which mean is connected to the Internet. It is a dynamic infrastructure for a global network, each device have an IP address (ID) that's allow to it to communicate with other devices.

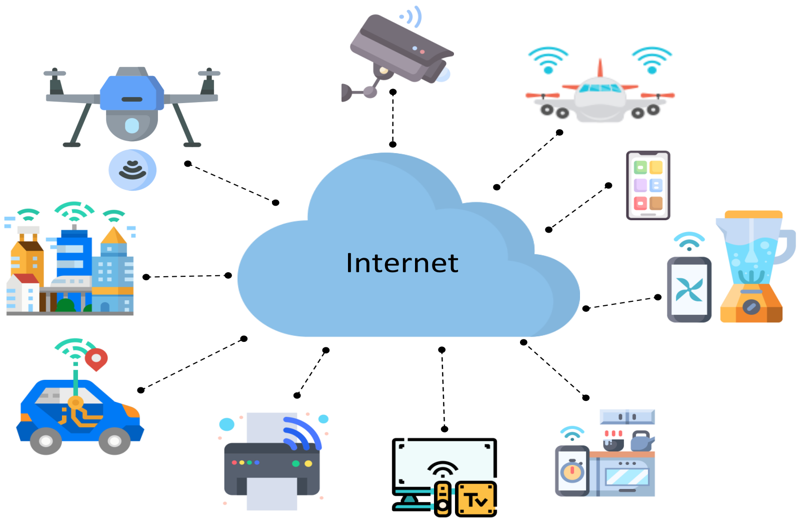


Figure 2.8: Internet of Things

- **How it work?** : The Figure 2.9 illustrate the IoT process cycle, the connected device (Thing) can send or receive data and based on data processing operation an action produce.

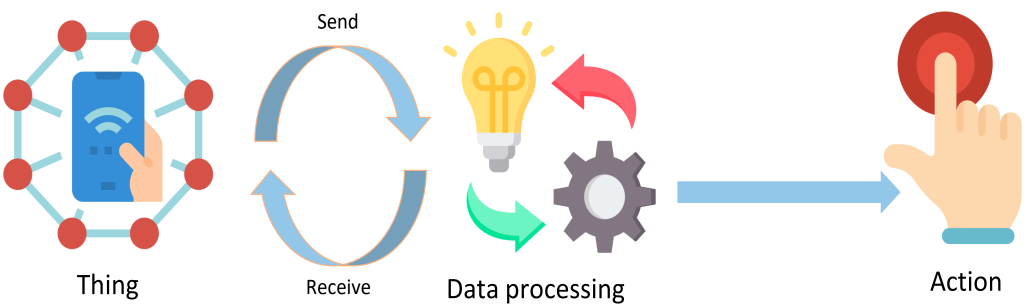


Figure 2.9: IoT Process Cycle

2.4.2 Mobile Edge Computing

Mobile Edge Computing (MEC) is one of the ways that become a result of how we can increase computing and storage performance?, specially with the increase of devices beside to new real time applications which need a very low latency. It brings the computing resources to mobile users at the edge network which allow to delay-sensitive applications to be quickly processed.
MEC can not be just a server with a fix position it can be also a car act as an MEC server and do computing and caching, UAVs, Smart building or any device nearby can play the role of the MEC server as long as it have enough resources (energy , space,. . . etc.) to execute the task and connected to the Internet [2].

Figure 2.10 and Table 2.3 present the difference between MCC & MEC which located from the proximity to the mobile device (User) or system architecture.

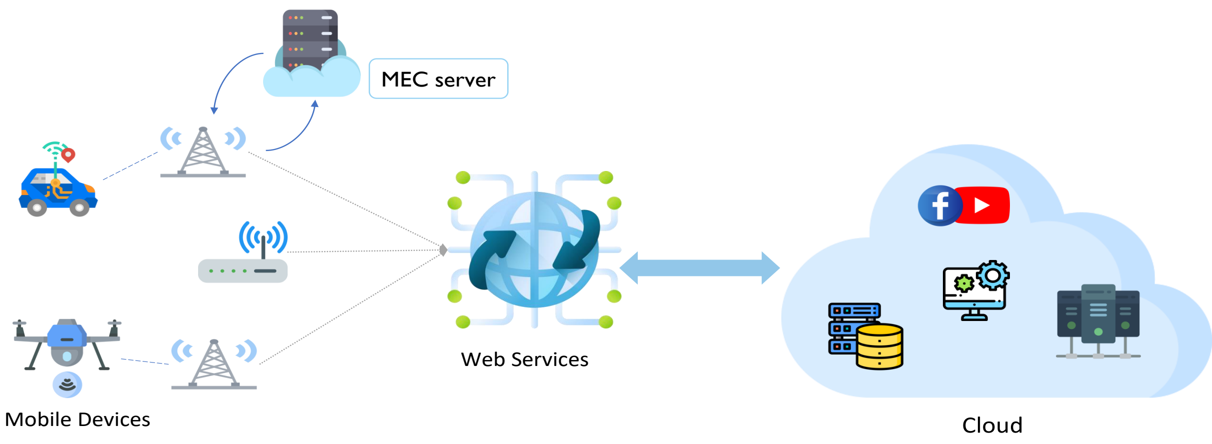


Figure 2.10: The Architecture of MCC & MEC [2]

Table 2.3: Comparison of MCC & MEC [2]

	Mobile Cloud Computing	Mobile Edge Computing
Physical Server	High computing and storage capabilities, located in large-scale data centers	Limited capabilities, collocated with base stations and gateways
Transmission distance	Usually far from users, from kilometers to thousands of kilometers	Quite close to users, from tens to hundreds of meters
System architecture	sophisticated configuration, highly centralized	Simple configuration, densely distributed
Application characteristics	Delay tolerant, computation intensive, e.g., Facebook, Twitter	Latency sensitive, computation intensive, e.g., autonomous driving, online gaming

2.4.3 Mobile Edge Computing Architecture

As Figure 2.11 shown, the deployment way of an MEC server can summarize three types of architecture : (i) 5G based architecture, (ii) decentralized architecture, and (iii) hybrid architecture.

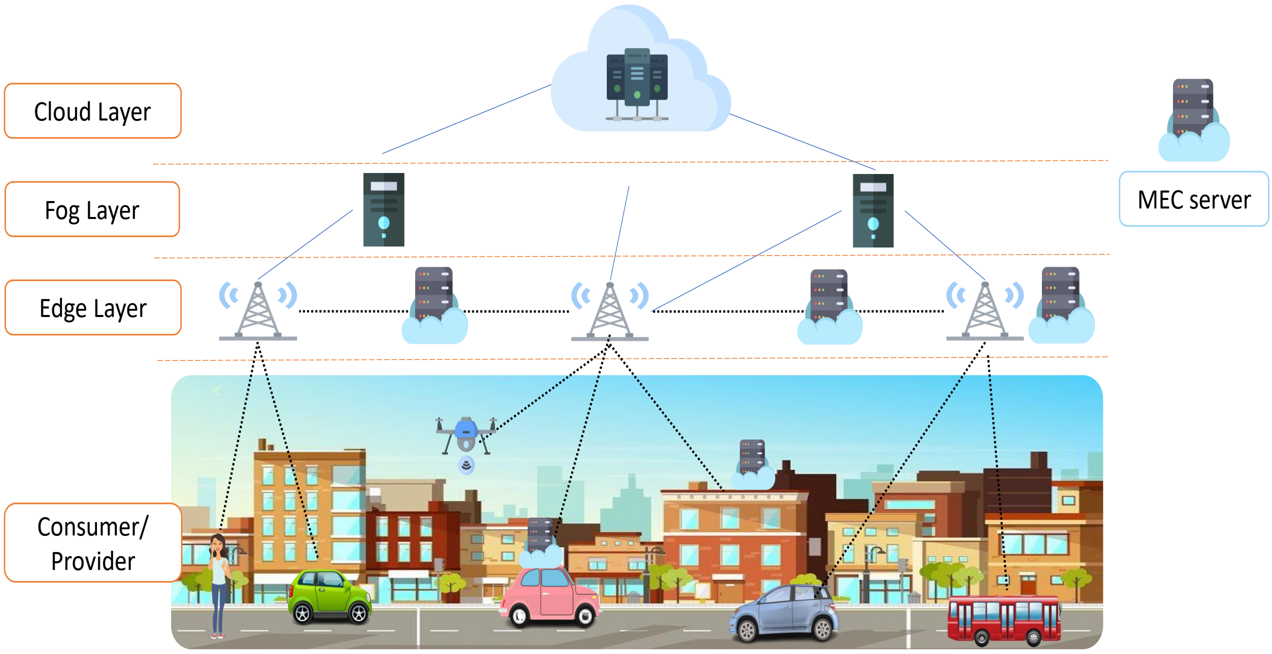


Figure 2.11: Mobile Edge Computing Deployment Architecture

1. **5G based Architecture :** The answer of the question "why we need 5G?" is quite simple, the human needs and the diversity of applications and its nature forced this jump [25]. Before the 5G settle down on a final architecture it pass with 2 versions (4G based architecture and non standalone architecture), although standalone architecture (Figure 2.12) is developed which is the stable version of 5G technology.

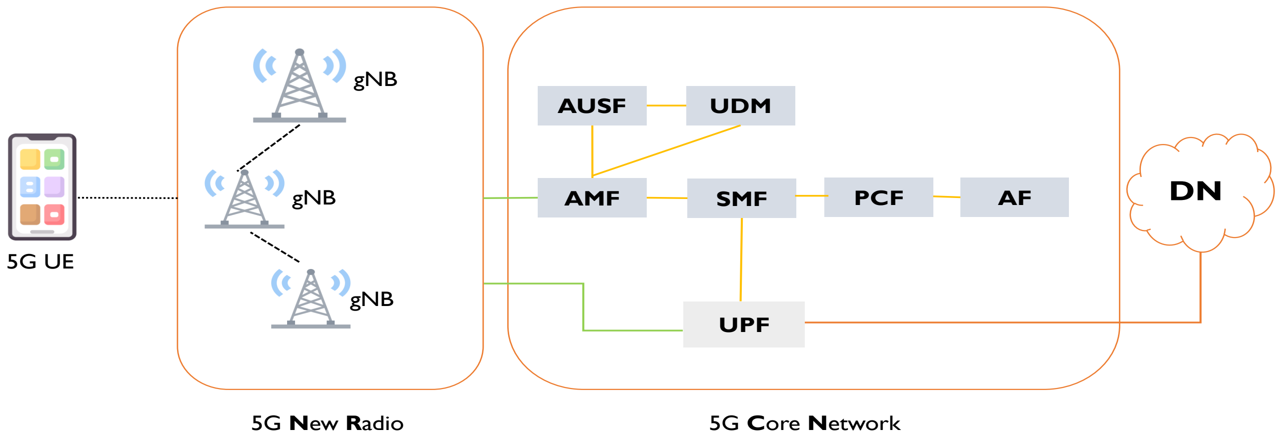


Figure 2.12: Standalone Architecture

   (a) **UE :** The user equipment is any device can communicate with the 5G radio access network (Smart car, UAV, Smart phone,...etc.)
   (b) **Radio Access Network :** Form the gNBs base station that transfer the user equipment signal to Core Network with the New Radio air interface, it can communicate with both Long Term Evolution (LTE) and New Radio (NR) radios.

(c) **Core Network :** It responsible for transmitter the control and user plane it contain:
- **AUSF :** Authentication server function.
- **UDM :** User Data Management.
- **AMF :** Access and Mobility Management Function.
- **SMF :** Session Management Function.
- **PCF :** Policy Control Function.
- **AF :** Application Function.
- **UPF :** User Plane Function.

(d) **DN :** Data Network express the Internet access and cloud services.

Until now all the versions that 5G pass through does not support the quality of service that we need (High Throughput, Low Latency and Connectivity) because of the existence of one of the 4G characteristics which is the access to Internet and cloud services via an intermediate (UPF) next to the long distance between the Data Network and the end user (Figure 2.13).

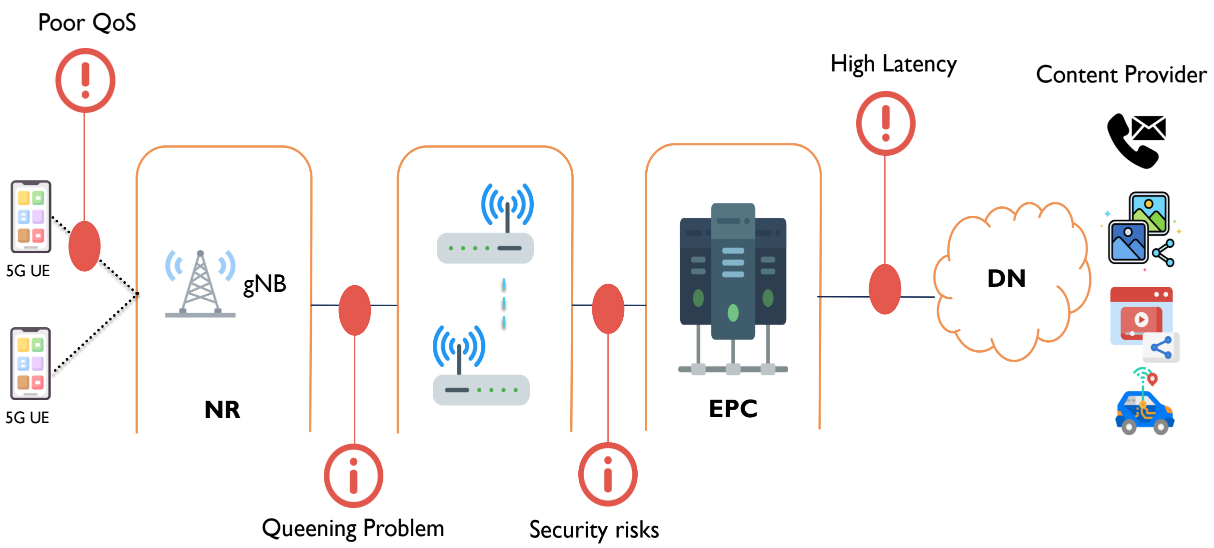


Figure 2.13: Problems face 5G

To solve this problem, a suggestion to add a new equipment to the 5G architecture is proposed, which is the integration of MEC server. The integration of MEC closer to the gNB base station as one of the deployment way, by doing that it jump to a high level from high speed, low latency and carry more and more of IoT devices number. Figure 2.14 illustrates the last version of integration of MEC closer to 5G architecture.

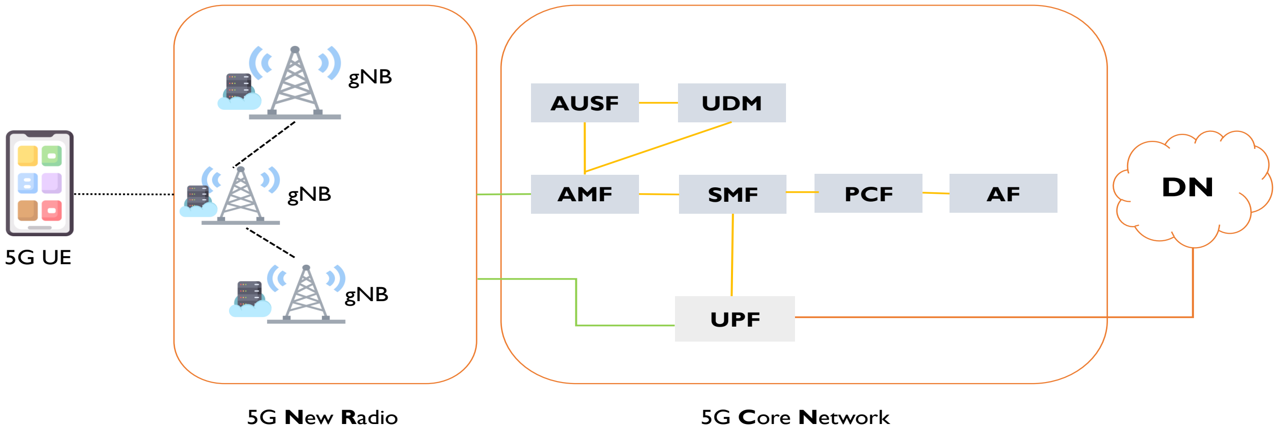


Figure 2.14: Standalone Architecture with MEC server (5G final version)

The fifth generation advantages are follow :

(a) High data rate about 10 Gb/s (Higher speed).

(b) Low latency.

(c) Best Quality Of Service.

(d) Involve Mobile Edge Computing.

(e) Support network heterogeneity.

(f) Spectrum Sharing [26].

2. **Decentralized architecture :** This architecture depend on set the MEC server far away from any base station it could be between two of them or more.

3. **Hybrid architecture :** Its a mix between the two previous architectures when the MEC server is located between two base stations or more and one of the base station is also supported with an MEC server. This architecture may be the powerful one from the side of low distance between it and the end user and the wide cover.

2.4.4 Mobile Edge Computing for UAVs Cloud

MEC has emerged as a promising solution to enable resource-limited mobile devices to execute real-time applications such as face recognition, augmented reality, and unmanned driving [2]. MEC research lies at the intersection of mobile computing and wireless communications, where the existence of many research opportunities has resulted in a highly active area [27].

With the new deployment of MEC server as a base station or an access point at the edge of networks [2]. So instead of reaching the main cloud for computing and running latency sensitive application its now possible to do all that just in minimal distance which is the edge of network.

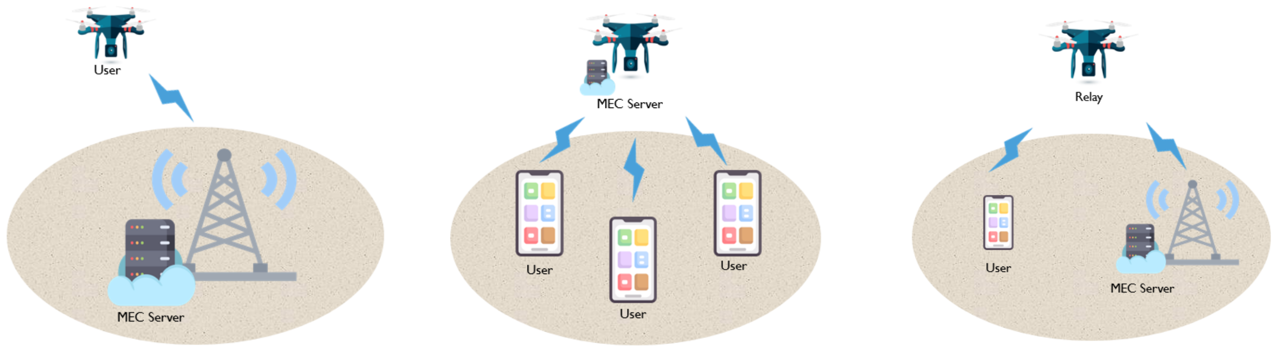
The different optimization objectives can be achieved through resource allocation where the MEC serves as a relay for UAVs Cloud, such as in user latency minimization, energy consumption minimization, and minimum throughput maximization [2, 28].

There are three ways how UAV interact with the MEC server as shown in Figure 2.15a.

a) Exploiting MEC computing capability.

b) Serving as MEC server.

c) Serving as a relay for MEC services.



(a) (b) (c)

Figure 2.15: MEC & UAVs cloud.

In our work we choose to benefit from the MEC server performance. Thus, we select the first interact which is exploiting MEC computing capability (Figure 2.15a) by using the 5G technology.

2.5 Selection of Services in MEC and UAV Clouds

Undeniably, the growth in the Internet speed for lower costs have contributed to the emergence of new Internet applications and services. CC reflects the exploitation of the hardware and software resources of remote computer servers across a network, usually the Internet. These servers are rented on demand, most often by usage band according to quality criteria (power, storage capacity, bandwidth, ...etc).

With the emergence of new real-time applications, MCC is introduced as an integration of CC into the mobile environment and which can be defined by an infrastructure where the storage and processing of data occurs outside of mobile equipment. This type of cloud allows access to services that are provided by the cloud computing environment anytime and anywhere from IoT mobile devices such as smartphones and tablets [24].

MEC is a new paradigm that provides an IoT service environment and CC capabilities at the edge of the network, within the radio access network, and in close proximity to mobile subscribers. The main purpose of MEC is to reduce backhaul network congestion, support low-latency applications, and offer an improved user experience.

In addition, UAV Clouds represents a particular class of MCC which combines the concept of CC and UAVs. It allows each UAV with it equipment's (sensors, cameras, ...) to offer and lease these resources as a service to clients, and thus to act as a mobile cloud server [2]. For example, a client can have information about any event directly from UAVs.

In the reality, there is a lot of UAVs service providers waiting the requests form clients to achieve it. And each service provider has a specific characteristics (such as cost and execution time). In this case we need to a service selection method to select the most suitable service provider for normal users.

2.6 Conclusion

In this chapter, we presented a background about UAVs, with their classification, applications, communication architectures and challenges. In addition, we introduced both CC and EC. In the next chapter, we will present and analyze the existing services' selection methods in UAV clouds.

3

Selection of Services in UAV Clouds: Related Work

Contents

3.1 Introduction

In the recent past years, many strategies have been proposed for UAVs to solve series of challenges that face UAVs to accomplish their tasks with full success and less cost such as Particle Swarm Optimization (PSO) [29], Genetic algorithms (GA) [4] and Fuzzy Logic Controllers (FLC) [30]. In addition the GT approach was tendency in last researches in UAV Wireless Communication Networks (U-WCN). Along with this chapter, we start with the presentation of some methods of services' selection in mobile and vehicular clouds. Then, we give an overview of game Theory. We also illustrate some of the existing GT strategies for UAVs clouds with a detailed synthesizing and comparison of all discussed methods.

3.2 Selection of Cloud Services in Wireless Networks

In the UAVs Cloud, when a service provider processes a service request, there are crucial Quality of Service (QoS) parameters to consider. For example, response time, cost, and reliability of service consumption. However, several service providers offer similar services but with different service qualities. This makes it difficult for consumers to choose the providers that best suit their needs. In the research literature, many service selection methods are proposed in MANET [16, 17] and VANET [18, 19, 20]. In addition many approaches are proposed for UAVs to solve many challenges that face UAVs to accomplish their tasks with full success and less cost such as PSO [29], GA [4] and FLC [30]. However, selection of services is poorly studied in UAVs cloud. To the best of our knowledge, only a one work can be found in the related literature addressing the selection of services in UAV clouds [8]. Authors of [8] proposed a GT approach for service's selection in UAVs cloud, which was dominate in last researches in U-WCN to what it provides of promising solutions in optimization UAVs challenges. The next Sections will present an overview of GT and analyze the GT methods in UAV cloud.

3.3 Game Theory: Background

Game Theory (GT) is a field of applied mathematics, that study the strategic interaction among multiple decisions makers, it deals with problems where players react with each other in order to maximize their gain [31] [3].
Formally, the GT is composed of three elements :

- A set of players $N = \{1, .., n\}$.
- Each player have a set of strategies $S_i = \{s_1, .., s_n\}$.
- Each strategy has a payoff function U_i.

3.3.1 Games Examples

- **Price War:** This kind of a GT in economics, we have two firms consider as a player that can keep high and stable price or start a price war this game organize as follows:
  - a) **Players:** Two firms.
  - b) **Strategies:** each firm can choose between two strategy : if the first firm reduce prices (start price war) it will see profits rise to 60 $ while the other firm who keeps prices high will get zero profits.Therefore, the firm who loses will also optimize their price like the first firm so they will take 3 $ profits from each firm.
  - c) **Pay-off:** is defined in this matrix as:

Firm A

Firm B	Stable	price war
stable	40$,40$	0$,60$
Price war	60$, 0$	3$,3$

Figure 3.1: Price War.

- **Prisoner's Dilemma :** is the most famous example of GT.This game between two criminals arrested for a crime and the police men have no any evidence about who done this crime.However,, to gain a confession they separate each other in chamber and question them.This game organize as follows

  a) **Players:** Two prisoners.

  b) **Strategies:** Each prisoner can choose between this strategy :
     - If both confess, they will each receive a 8 month.
     - If Prisoner 1 confesses but prisoner 2 does not, prisoner 1 will be free and prisoner 2 will get 12 month .
     - If neither confesses, each will serve one month .

  c) **Pay-off:** is defined in this matrix as:

Player A

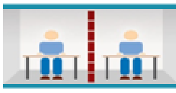
 Player B	keep quit	confess
keep quit	-1 , 1	-12 ,0
Confess	0 ,-12	-8 , -8

Figure 3.2: Prisoner's Dilemma.

3.3.2 Types of Games

In general, GT models can be also divided into two main categories:

a) **Cooperative Game (CG):** Is when the game players play together and take action as a group.The players in each group cooperate with each other while the groups are compete with other groups we can take example of a cooperative game for UAVs Network Security, Task Allocation,Data Collecting and Routing. [3].

b) **Non-Cooperative Game (N-CG):** Unlike cooperative game, a Non-Cooperative Game is a game where each individual player compete with each other to maximize his own payoff or to minimize his cost. This type of games are mainly applied in wireless communications with UAVs networks such as problem of UAVs in order to maximize the coverage of mobile devices[3].

3.3.3 Nash Equilibrium

The Nash Equilibrium (Named after John Nash who first described it) is important concept in GT that defined as kind of solution of a game that contains two or more players, each player have one strategy where no player have chance to change his own strategy according to what the other players think because he will not win anything or he would get a less payoff when changing it strategy.

a) **Pure Strategy Nash Equilibrium :**
We use Pure Strategy Nash Equilibrium when players can not mixed between more then one strategy.

b) **A Mixed Strategy Nash Equilibrium :**
We use Mixed Strategy Nash Equilibrium when players can mixed between more then one pure strategy.

3.4 Game theory in UAVs-assisted Wireless Communication: Related Work

UAVs have many advantages for wireless communication networks like Quality Aerial Imaging (big size data transmission), easily deploy-able (for hard accessible areas) and security when the matter is a natural disaster (Gathering data during and after the event). However, U-WCN have many challenges such as energy consumption, delay, height, and coverage. In this Section, we discuss the effect of GT approaches in U-WCN. According to type of game, we classified GT approaches into two mains categories: (i) Cooperative GT and (ii) Non-Cooperative GT as shown in Figure 3.3.

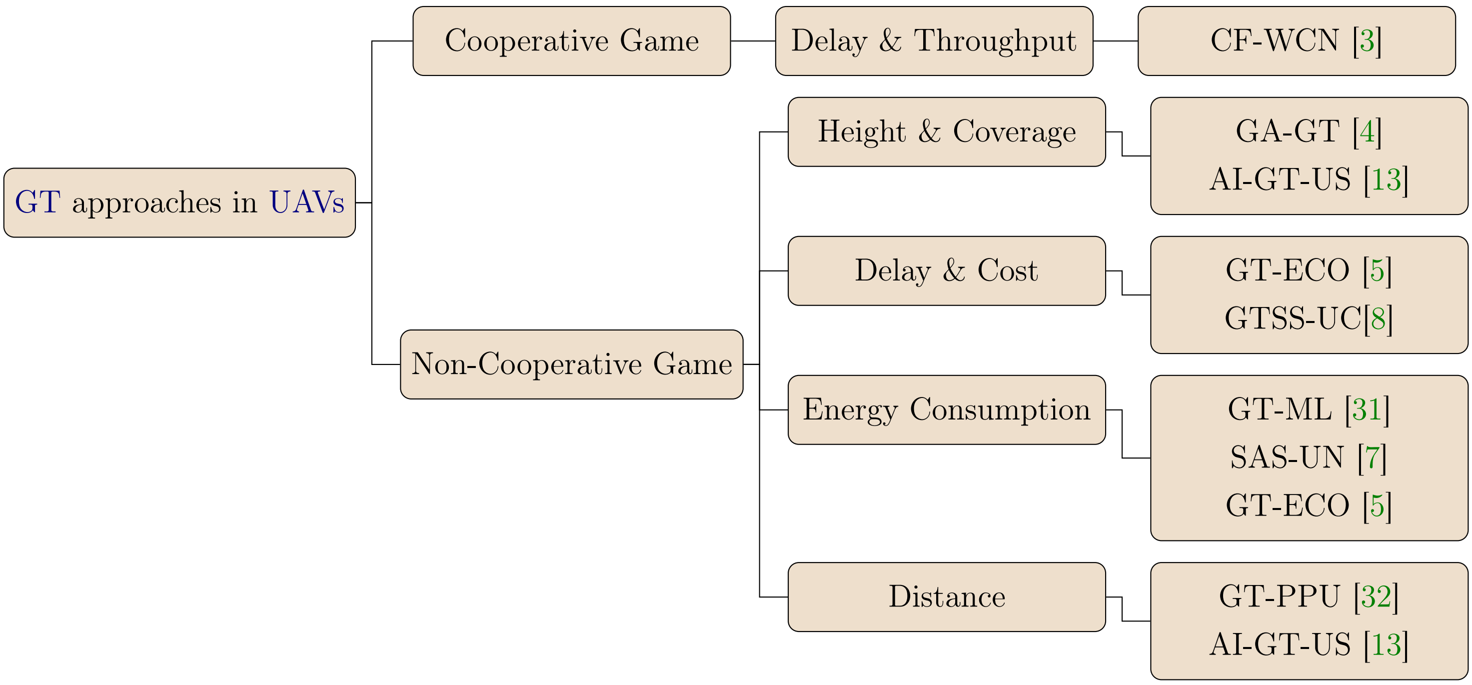


Figure 3.3: Classification of the GT approaches with UAVs network

3.4.1 Cooperative Game

UAV is the main component of UAS, it can do many tasks such as : collecting, sending, receiving and delivering data. In wireless communication UAV, we have some of tasks are execute by one UAV or by a swarm of UAV, and some of theme not allocated to any UAV. The main problem in this case is how to organizing and allocating tasks to UAV?, to answer this question Walid Saad et al., proposed in [33] a GT for modeling a hedonistic coalition formation game between agents and tasks.

- Agents (UAVs) and tasks can consider as a players.
- Agents works as a relay that moves in a coalition between the different tasks to forward and transmits the packets to a common receiver.
- The tasks can be a group of mobile device that send requests to UAV .
- The players can leave or join the group based on their preference in term of reducing throughput and delay.
- The payoff of this game divided among the players which is the execution of the task with a high quality based on throughput and the cost based on delay are take to serving this task.
- **Advantages :**
  - It takes into consideration the quality of task in term of throughput and delay.
  - This protocol ensures load balancing between UAVs.
- **Drawbacks :**
  - Does not take into consideration challenges such as power consumption and security.

3.4.2 Non-Cooperative Game

a) **Optimal Height and Coverage :** GT concept is used to reach the optimal height and coverage in wireless communication of UAVs with 3D mobility. For instance, Mbazingwa et al proposed in [3] a N-CG to define the optimal position of two UAV that offer communication to different mobile user as shown in Fig 3.4.

   - Each UAV (player) have two strategies (actions) to cover mobile user.
   - The first strategy about the next position that the UAV can take.
   - The second strategy about the change of altitude during maneuver.
   - The payoff of each UAV is to choose the best strategy in term of number of mobile user they can support.

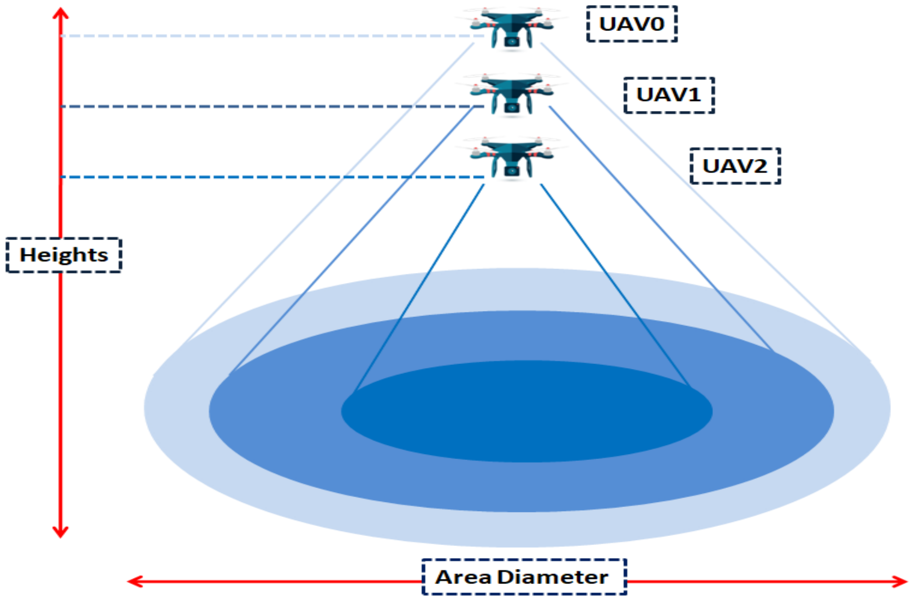


Figure 3.4: Area coverage from different heights of UAV[3].

In addition, Giagkos et al proposed in [4] a dynamic mobile network by replacing the static land Base Station (BS) by flying UAVs will be a great solution in granting a set of wished features such as reducing power consumption and increasing bandwidth. This paper compare two methods that allow to a small of Hydrocarbon-Powered Meduim Altitude Long Endurance (MALE) UAVs to build a flying maneuvers respecting ground-based mobiles quickly movement. The set of UAVs must automatically relocate their positions in simultaneous way with the ground-based mobiles with the objective of increasing the area coverage and with consideration of the remain communication power. So the main problem is how to coordinate this set of UAVs by choosing the best next position (Location) in order to reach optimal height, widely coverage with maximum users with less power consumption and free collision (Between UAVs). The problem description is as follows :

- A set of UAVs $U = \{1, .., u\}$.
- A set of mobiles in the scenario $G = \{1, .., g\}$.
- Let $\mathbb{C} \subseteq G$ be a set of mobiles covered by $u \in U$.

$\forall g \in \mathbb{C}$, u is ensured to expend power p_g^u to support communication link between theme and P_{max}^u is the maximum available power for u . So the formula is to : maximize $f(\sum_1^{n\in|U|} |\mathbb{C}|)$

$$U = \{g \mid g \in G\}.$$

$$\forall \ C \in \mathbb{C} \mid C \cup C\prime = \emptyset.$$

$$\forall \ u \in U \mid \sum_{g=1}^{|C|} p_g^u \leqslant P_{max}^u$$ [4]

The GT choose the N-CG to simulate this problem. So it design for each player (i.e UAV) has a series of next potential location A and series of payoff C that represent the numbers of ground-bases mobile that are supported by that UAV as shown in 3.5 :

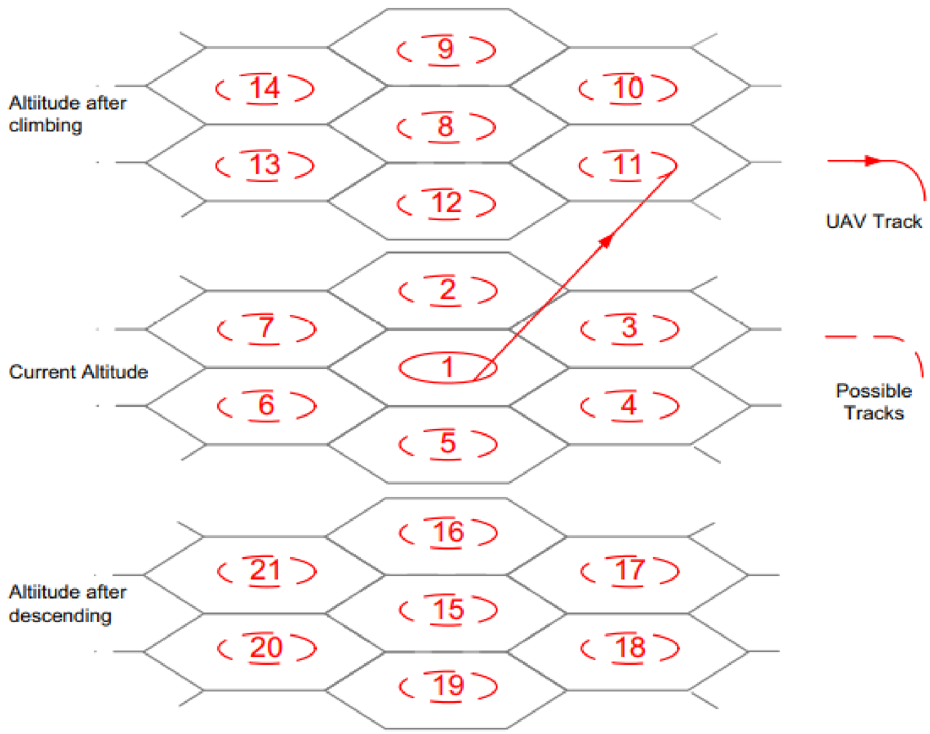


Figure 3.5: Game strategies for a single UAV. The dotted circles refer to the possible tracks. Continuous line circles refer to the current track [4]

As we said A is a set of next position as the Figure 3.5 chows that each UAV have the following choices: it can stay in cell 1 and move in circle way or reposition in one of the adjacent cells $2-7$, or climb to one of maximum climb rate and circle in $8-14$ cells ,either it can descend in circle way to the $15-21$ cells. That's give for every UAV a series of 21 of actions [4].

- **Advantages :**
  - This method uses the UAV as a BS to reach a high coverage.
  - The simulation results show that this method gives more effective results than GA.
- **Drawbacks :**
  - It does not take into consideration energy consumption.
  - It study the perfect next position of the UAV that give the high coverage but ignore the physique collision that could happen between them or with the path obstacles.

b) **Energy Saving and Power Optimization :** The major challenges of UAVs is energy consumption. UAVs consume power due to the development of application that need high

throughput and data with a best QoS such as video streaming that take more energy, the communication links between U2U, U2G, SATCOM and UAVs to mobile also consumed more and more energy. This problem is formulated as a sub-modular GT approach for optimizing energy. Koulali et al proposed in [7, 31] a Periodic Beaconing for UAV Networks by considered UAV as aerial base station in wireless communication system. Each UAV send a beacon message to provide a coverage to the mobile on the ground. The game is defined as follows :
$G = \{N_i, A_i, U_i\}$ where:

- N_i : A set of UAVs, we are in this case two UAVs.
- A_i: UAVi fixed its beacon period τ_i comprised between zero and T as : $A_i = [0, T]$, where a value of 0 indicate that UAVi not perform to contact user mobile on the ground while a value of T indicate that UAVi perform active beaconing for user mobile all the time.
- U_i : Is the payoff of each UAV which is a function defined as the deference between

  a successful first contact with mobile users and consumed energy in beacon period

  duration.This function denoted as :

$$u_i^i(\tau_i, \tau_j) = \begin{cases} P_i^s(\tau_i, \tau_j) - \frac{(C_{b\tau_i} + C_s)l}{m} \\ m = T * l \end{cases}$$

Table 3.1: Describing function of payoff[7]

Giving Letter	Meaning
m=l*T	the available time window for UAVs to contact with mobile devices
T	is the beaconing period duration for UAVi
l	is a constant
(τ_i, τ_j)	beacon period duration for UAVi, UAVj respectively
$P_i^s(\tau_i, \tau_j)$	the probability of the twoUAV choosing the beaconing duration τ_i and τ_i
C_b	the energy cost per slot for sending beacons
C_s	energy cost for remaining switching the transceiver state

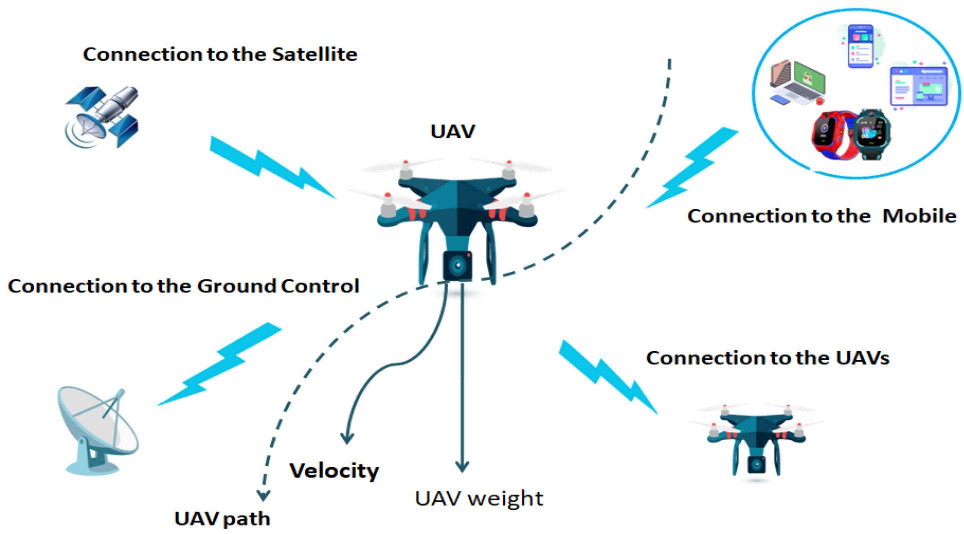


Figure 3.6: Different ways by which UAV consume energy[3]

- **Advantages :**
  - This protocol can provide the performance of optimization significantly the power consumption.
  - The use of unmanned aerial vehicle as Aerial Base Stations (ABSs) for supporting the communication traffic growth.
- **Drawbacks :**
  - It does not take into consideration optimal altitude parameter to cover maximum number of devices.

c) **Path planing problem in UAVs network :** The multiple route obstacles make the path planing rather difficult. Diksha et al considered this kind of issue in their paper [32]. The classic methods for solve those problems still common like Artificial Intelligence (AI)-based technique, except that is unfortunately slow in term of time and energy consumption. Boroujerdian et al presented in [34] that with the bad choice of algorithm or its input can lead to route that can take four times longer to traverse which is waste if time and power that both of them important to runtime applications. So instead of that they use GT approach to minimize the total time that the UAV need's to reach to destination and to do so is by minimize the hover time (HT) which is the time that the UAV need to take decision related by route obstacles and flight time (FT) which is the time taken to reach destination point. It is related to the traveled distance, also called path length (PL).
To summarize all things, they applied two methods for better path planing, first one is Rapidly-exploring Random Tree (RRT) common algorithm for Robot Path Planing (RPT), the second is converting the problem into a game precisely Nash equilibrium strategy. The problem description is as follow:

- Split the RRT path planing algorithm parameters into independents and dependents parameters.

(a) The independents are the **Players**.
(b) The dependents will be used in combination with the independents parameters to formulate the **payoffs** of the players.

- The payoffs of the players is a function of two objectives altruistic and selfish.
  (a) The **altruistic objective** of the players is to reduce PL and HT that's lead to reduce power consuming.
  (b) The **selfish objective** of the players depend on their own parameters.

In this problem, GT proved its efficiency by (5-21%) more optimal in term of time taken (HT & PL) to find the best solution. In addition amelioration between (15-57%) in planning time [32].

- **Advantages :**
  - Using GT approach led to a better results in term of path planing that lead to a less taken time.
  - Faster reaction when it is about route obstacles.
- **Drawbacks :**
  - Energy consumption was not taken into consideration as a parameter.

Controlling a group of UAVs directed to a specific task not rather easy, Janusz Kusyk et al studied in [13] how to benefit from this popular solution technique in control swarm UAVs problem such as collision avoidance, routing, and UAVs communication setup.
The main problem here is how a swarm members shape and preserve a MANET nodes in constantly changing location, during the same time avert and tracking a mobile electromagnetic sender beside how to avoid other swarms members.
They combine both of Bio-inspired Computing (BiC) (GA method) and GT (N-CG type) based flight control.
They called the BiC by evolutionary flight control (EFC) and N-CG by non-cooperative decision game (NCGD), basically the output of the first is the input of the second. What happen is the **EFC** apply in each UAV to extract a group of candidates to improve next location for the UAV depend on its neighbor local information, those candidates are the input of **NCDG** as a strategies, to calculate the payoffs of each players [13]. The game setup for an UAV n_i to determinate its next location as follows :

- $\Gamma_i(t) = \langle P, S, U \rangle$ where t is time :
  - P is a set of players which is define by $P = n_i \cup \mathcal{N}_i(t)$.
  - S is a strategy profiles area that's equal: $S = X_{n_k \in P} S_k$ with $S_k = \Lambda^L \cup P_k$.
  - U it is the players payoff which is Von Nuemann–Morganstern function [13] [35].

Moreover, authors of [13] studied the effect of conjunction of two optimization algorithms **EFC** & **NCDG** to ameliorate a UAVs swarm control and with this two algorithms execute on each UAV to place it self in the swarm, so that can follow a set of connected MANET, beside to keep away or tracking an electromagnetic transmitter.

- **Advantages :**
  - Well controlling a swarm of UAV maintain a set of MANET.

  - Reducing energy consumption of the swarm members consequence of optimizing the path length.

- **Drawbacks :**
  - Does not take into consideration the security factor if a malicious neighbor send erroneous information.

d) **Delay and Cost :**

- **Offloading Problem in UAV Network :** The energy consumption is important element in each device because each node contains a battery with a limited power. In any network all device mobile need to exchange message in each other via wireless communication. However, the essential event which is influence in energy power is the offloading problem that include two different kinds : Problem of computation offloading and data offloading problem (i.e : video reprocessing) we note that first kind is a relation with the communication delay.Therefore, all this technique work to reduce power consumption. Mohamed-Ayoub Messous et al proposed in [5] a GT for solve this kind of problem.
  - **Describing the component of Game :** The GT in this kind of offloading problem are denoted as follows [31] [5]:
    - ∗ Players : A set of UAVs navigate in a same geographic zone.
    - ∗ Strategies : Each UAV use three pure strategy denoted as :
    (a) Perform their tasks locally.
    (b) Offload them via a local. wireless connection to a GBS.
    (c) Transfer through a cellular connection to an Edge Server (ES).

    ∗ Pay-off: Defined as a utility that contains a combination of energy, delay

    and computation cost denoted as follow :

$$U = \alpha \sum_{i=0}^{N} T_i + \beta \sum_{i=0}^{N} E_i + \gamma \sum_{i=0}^{N} C_i$$

  Where :
    - ∗ α, β and γ represent respectively the weighting parameters of delay, energy consumption and communication cost. The parameter α is increased in order to optimize delay while β must be augmented in order to save more energy and parameter of γ should be increased or decreased according to the availability cellular communication offer, also this weighting parameters function defined as :
    $\alpha + \beta + \gamma = 1$.
    - ∗ N: Number of tasks.
    - ∗ T_i, E_i, C_i : Represent the time, energy and cost respectively.
  - **Communication and Computation Model :** In Figure 3.7 below we consider drone with a cellular network access used to communicate with GBS .While when UAV need to navigate with ES by a cellular network (Third Generation (3G)/LTE).However,in computation model we take that each

UAVcan execute more then one task while each task defined as :(C_i, D_i) , C_i is the number of computation cycle and D_i represent the size of data .Any drone can execute their task locally or forward theme to base station. For this kind we defined three strategies with a different utility function for each UAVi depend on their strategy are take [31]:

$$U_i(s_j, S_{-j}) = \begin{cases} U_{local} = \alpha E_{local} + \beta T_{local} + \gamma C_{local} & if \;\; s_i = Localcomputing \\ U_{local} = \alpha E_{ES} + \beta T_{ES} + \gamma C_{ES} & if \;\; s_i = OffloadingtoES \\ U_{local} = \alpha E_{BS} + \beta T_{BS} + \gamma C_{BS} & if \;\; s_i = OffloadingtoBS \end{cases}$$

Where E_{text} , T_{text} , C_{text} are the energy consumption, time delay and computation cost for three strategy :

(a) **Local Computing :** Some computation task can execute locally in UAV without sent to another equipment.So the utility function for $T_i = (C_i, D_i)$ calculated by :The computation power used in the device for example : CPU frequency which is the number of computation cycles per a time unit denoted as : F^{CPU}_{local} with its consumed energy e^{CPU}_{local} :

$$\begin{cases} T_{local} = C_i / F^{local}_{CPU} \\ E_{local} = C_i * e^{local}_{CPU} \end{cases}$$

(b) **Offloading to the ES :** The first technique of offloading problem is to send the computation task to ES via cellular access network3G. The delay required for execution this task will be increased due to time necessary for forwarding data to ES.So the utility function for $T_i = (C_i, D_i)$ calculated by :

$$\begin{cases} T_{ES} = (C_i / F^{ES}_{CPU}) + (D_i / R_{Cellular}) \\ E_{ES} = D_i * e_{Cellular} \\ C_{ES} = D_i * c_{Cellular} \end{cases}$$

F^{CPU}_{ES} is the frequency of the server,E_{ES} is the energy required for transmission data to ES ,$R_{Cellular}$ is the effective data rate achieved in the cellular network and $e_{Cellular}$, $c_{Cellular}$ represent the energy consumed ,cost respectively when send one data in cellular network to ES.

(c) **Offloading to the BS :** The second technique of offloading problem is to send the computation task to BS via wireless access point. The delay and energy required for execute this task will be more consumed.So the utility function for $T_i = (C_i, D_i)$ is defined by : F^{BS}_{CPU} is the frequency of BS ,E_{ES} is the energy required for transmission data to BS ,R_{wi-fi} is the effective data rate achieved in Wireless Local Area Network (WLAN) and e_{wi-fi} , c_{wi-fi} represent the energy consumed ,cost respectively when send one data using wireless access point to BS denoted as :

$$\begin{cases} T_{BS} = (C_i / F^{BS}_{CPU}) + (D_i / R_{wi-fi}) \\ E_{BS} = D_i * e_{wi-fi} \\ C_{BS} = D_i * c_{wi-fi} \end{cases}$$

∗ **Advantages :**

  · It takes into consideration the important parameter in term of delay, energy and cost.
  · Using MEC as edge server to optimizing delay.

* **Drawbacks :**
  · Offloading problem is classified into two main brunches : Computation and data offloading problem. In this paper discuss the kind of computation offloading but does not take into consideration the data offloading problem.

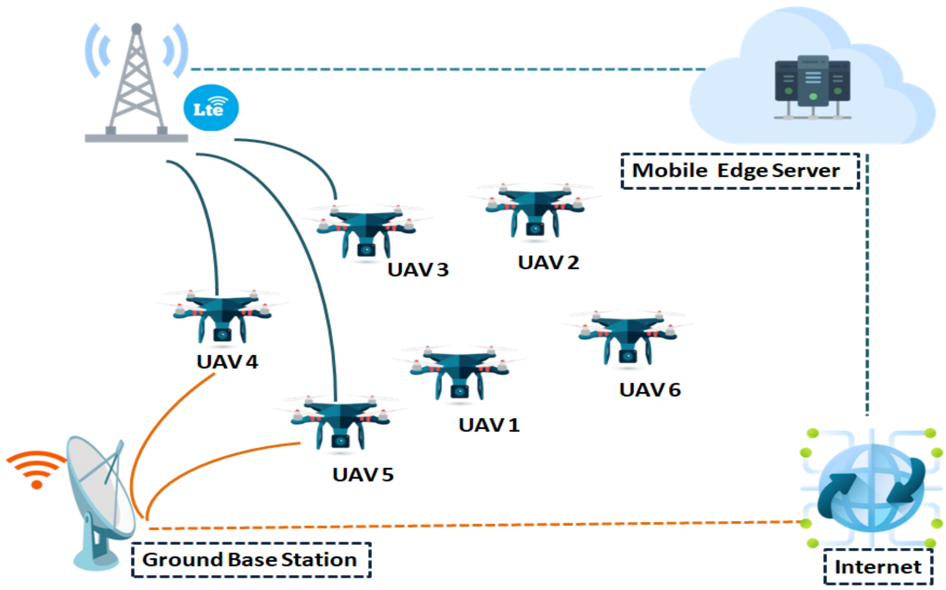


Figure 3.7: System Architecture [5].

- **Selection of Services in UAV clouds :** GT is an approach of optimization method can used for selection services in UAV cloud, to help the requester to choose the best service provider in term of QoS and price. Rezigat et al proposed in [8] GT an approach for selection service UAVs in clouds by describing the game as follows :
  – Players : $\{UAV, R\}$ Two players which UAV is service provider and R is a requester.
  – Strategies : Each player have two strategy,the R check between Consume (C) or Not Consume (NC) according to the price and QoS proposed by service provider while a service provider choose between Offer (O) and Not Offer(NO) the service .However , the price is defined according to the QoS needed by a R.Each player take the best strategy to maximize their gain.They use a Nash Equilibrium (NE) to balance the game.
  – Pay-off : To determine the gain of each player (shown in table 3.2) we need to define some parameter like :
    * **Reputation Q_{REP} :** Its value depend the opinion of requester R_i about the service provider (s) defined by service provider which is execute the service. $Q_{REP}(s) = \frac{\sum_{i=1}^{n} R_i}{n}$, $R_i \in [0, 1]$ and (n) represent the number of requester.

* **The execution time** Q_{ET} **:** Which is the delay necessary for executing service determined by:the combination of processing and transmission time denoted as: $Q_{ET} = T_{Rrocess}(s) + T_{Trans}(s)$

* **The energy consumption** Q_{EN} : Which is the energy consumed for executing service determined by: the combination of processing and transmission power denoted as: $Q_{EN} = E_{Rrocess}(s) + E_{Trans}(s)$

* **The cost of execution price** Q_{EP} **:**The price of service defined by service provider.

Where:

(a) **N**: Number of service data packet.

(b) X_{11},Y_{11} :Represent the gain of service provider,requester respectively when the service provider offer the service and the requester will be consumed.

$$\begin{cases} X_{11} = N * Q_{EP} - (Q_{ET} + Q_{EN}) \\ Y_{11} = N - (Q_{ET} + N * Q_{EP}) \end{cases}$$

(c) X_{12}, Y_{12} : Represent the gain of service provider,requester respectively when the service provider offer its service while the requester not consumed and **M** is the number of times when the requester refused to consume a service.

$$\begin{cases} X_{12} = -N * Q_{EP} \\ Y_{12} = -M * N \end{cases}$$

(d) X_{21},Y_{21} :Represent the gain of service provider,requester respectively when the service provider could not offer its service while the requester need to consumed and **L** the number of times when the service provider refused to offer a service.

$$\begin{cases} X_{21} = 0 \quad (Busy) \\ X_{21} = -N * L * Q_{EP} \quad (Else) \\ Y_{21} = -N \end{cases}$$

(e) X_{22},Y_{22} : Represent the gain of service provider,requester respectively when the service provider could not offer its service and the requester could not need to consumed.

$$\begin{cases} X_{22} = 0 \\ Y_{22} = 0 \end{cases}$$

Table 3.2: Pay-off matrix of UAV and R [8].

UAV / R	**C**	**NC**	
O	(X_{11}, Y_{11})	(X_{12}, Y_{12})	p
NO	(X_{21}, Y_{21})	(X_{22}, Y_{22})	$1-p$
	q	$1-q$	

  - p is the probabilities when the Service provider choose Offer strategy and $1-p$ when choose No Offer strategy, q and $1-q$ are the probabilities that the Requester select strategies Consume and No Consume respectively.

- **Advantages :**
  - This method reduces average delay and takes into consideration price and quality of experience.
- **Drawbacks :**
  - It does not take into consideration power consumption.

3.5 Comparison and summary

In this section, a comparative study of GT protocols is presented. Table 3.3 summarizes the main characteristics of the discussed categories, where GT protocols are classified according to their QoS requirements, and other criteria such as energy awareness, simulator, path planing, cost, height and coverage.

By studying these methods and as presented before, we can say that the throughput and the energy awareness are poorly studies in the selection of services in UAV clouds. For instance, GT-ECO [5] takes into consideration the most important factors such as energy awareness, delay, and cost parameters. However, this solution can not suitable for selections' service in UAV clouds. In addition, the only one work can be found in the related literature addressing the selection of services in UAV clouds [8], which can taken into consideration both delay and cost. However, this method not address the energy awareness, that is what motivated us to propose our new non-cooperative game-based method (GTCS-MU), which addresses the aforementioned issues (delay, throughput, cost, and energy). The following chapter describes the details of our contribution.

Table 3.3: GT protocols in UAV networks.

		QoS parameter			Other Criteria				
GT approach-based	Methods	Delay	Throughput	Cost	Energy awareness	Height & Coverage	Distance	MEC-enabled	Simulator
Cooperative Game	**CF-WCN [33]**	✓	✓	✗	✗	✗	✗	✗	Not mentioned
Non-Cooperative Game	**GT-ECO [5]**	✓	✗	✓	✓	✗	✗	✓	Not mentioned
	GT-PPU [32]	✗	✗	✗	✗	✗	✓	✗	Not mentioned
	GA-GT [4]	✗	✗	✗	✗	✓	✗	✗	GAZEBO
	SAS-UN [7]	✗	✗	✗	✗	✓	✗	✗	MATLAB
	AI-GT-US [13]	✗	✗	✗	✗	✓	✓	✗	OPNET
	GTSS-UC [24]	✓	✗	✓	✗	✗	✗	✗	NS-2
	GTCS-MU	✓	✓	✓	✓	✓	✗	✓	OMNet++

4

Selection of Cloud Services in MEC and UAV enabled Networks: Our contribution

Contents

4.1 Introduction

The essential parameter in UAV Clouds is the QoS parameters. QoS depends on the cost, duration of execution and throughput consumption of tasks, these characteristics will be better to take into consideration when executing a task by a service provider.
In this chapter, we present our new non-cooperative Game Theory method for Cloud Services in MEC and UAV enabled networks (GTCS-MU). Our main aim is to help requester to select the best service provider in term of cost, duration execution, throughput and energy. The results of our simulations conducted using OMNeT++ simulator [36] depict the good performance of our solution.

The rest of this chapter is organized as follow : We present our contribution GTCS-MU with development of our different strategies. Then, we discuss our various scenarios. In addition, we evaluate and discuss the performance of our proposed method.

4.2 Game Theory for Cloud Services In MEC and UAV network: Our contribution

In this section, we discuss the details of our contribution.

4.2.1 System Model of GTCS-MU

In our contribution, we consider that the network contains a set of UAVs with set of requesters R, the UAVs identified as a services providers. The service provider can offer a set of tasks to requesters R which can consume or not depending on their requirements. In addition, we have multiple service providers with various of QoS requirements. We consider the GT in our solution as follow :

- **Players :** $\{UAVs, R\}$ which is service providers and a requesters respectively.
- **Strategies :** Each player have two strategies :
  - The Requester R_i check between Consume (C) or Do Not Consume (NC) depends on QoS requirements (throughput and duration of execution) offered by a service provider and QoE (cost).
  - The service provider UAV_i check between Offer (O) or Not Offer (NO) his task to requester.

  Each UAV_i saved it offer in MEC server. Also, we choose to excute the GT in MEC server to ensure the efficiently of our method.
- **Pay-off :** Each player choose the best appropriate strategy in order to maximize it's gain. We can use a pay-off in form of matrix or tree as a way to determine the gain of each player in the game. Table 4.1 illustrates the payoff matrix of service provider and requester, where p and $(1-p)$ are the probabilities that the service provider selects strategy **O** or **NO**, respectively. q and $(1-q)$ are the probabilities that the requester selects strategy **C** or **NC**.

Table 4.1: Payoff matrix of UAV and R.

UAV / R	Consume	Not Consume	Probability-UAV
Offer	(A_1, B_1)	(A_2, B_2)	p
Not Offer	(A_3, B_3)	(A_4, B_4)	$1-p$
Probability-R	q	$1-q$	

To determine the reward of each player, we discuss the following parameters :

a) **I :** Each task represent by a number of data packets that will be exchanged between players $\{UAV, R\}$.

b) **Price of Task :** The price of the task is determined by the service provider.

c) **Throughput :** The throughput[1] that tells you how much data was transferred from a source (service provider) at any given time.

d) **Duration time :** The duration time is the combination of signal propagation delay (it can be negligible in this case), max time queuing will be take, the time frame necessary for transmitted data from source (UAV) to destination (BS), and processing time of the task, which is given by:

$$D_t^{ToT} = D_t^{Queuing} + \frac{Data}{t_{th}} + D_t^{Process} \tag{4.1}$$

e) **Energy consumption :** The energy consumption to offer the task (t) defined as energy consumption to transmit and receive the data packets. The energy consumption is then calculated by:

$$\begin{aligned} \text{E}_{\ Tot} &= E_r + E_t \\ &= P_r^{uav} * T_r + P_t^{uav} * T_{tr} \\ &= \tfrac{(P_t^{BS} * G_{uav} * G_{BS} \lambda^2)}{(4\pi D)^2} * T_r + P_t^{uav} * T_{tr} \end{aligned} \tag{4.2}$$

[1] This metric represents the total amount of data a receiver actually receives from the sender divided by the time taken by the receiver to obtain the last bit.

Table 4.2: Notations and Meaning

Notations	Meaning
t_{Price}	The price of the task.
E_{Tot}	The total energy consumption.
E_t	The energy consumption to transmit data.
E_r	The energy consumption to receive data.
t_{th}	The throughput of the task.
$D_t^{Process}$	The delay necessary to serve the task.
$D_t^{Queuing}$	Represent the max time queuing.
D_t^{ToT}	The total delay necessary to execute the task.
P_t^{uav}	Power transmitted by the UAV
P_t^{BS}	Power transmitted by the BS.
P_r^{uav}	Power received by the UAV.
G_{uav}, G_{BS}	Gain of base station and UAV $G_{uav} = G_{BS} = 1$
C	Represent the light speed which is equal: $3 * 10^8$
λ	Represent the wavelength $\lambda = \frac{C}{F}$.
T_r	Represent the time receiving e.g: ACK.
T_{tr}	Represent the time necessary to transmit a task.
D	Represent the distance between UAV and BS defined as :
	$D = \sqrt{(X_{uav} - X_{BS})^2 + (Y_{uav} - Y_{BS})^2 + (Z_{uav} - Z_{BS})^2}$.
$Data$	The total data of task that equal: $I * \lvert packet \rvert$.

4.2.2 Development of Our Strategies

- **Combination of strategies (Offer and Consume) :**
  - $A_1 = [I * t_{Price}] - (D_t^{ToT} + E_t^{Tot} + t_{th})$
  - $B_1 = I - (D_t^{ToT} + I * t_{Price})$

  In this case, the MEC server received and saved offers of UAVs while the requester needs to consume it. A_1 illustrates the reward of service provider UAV which is calculated by the number of data packets multiplied by the price of each packet. In addition, it influence by the duration time, energy, and throughput necessary for serving the task. On the other hand B_1 represents the gain of requester rewards to the task consumed in term of data packet, also it influence by the price and duration time of total task.

- **Combination of strategies (Offer and Do not consume) :**
  - $A_2 = 0$
  - $B_2 = 0$

  In this case, the MEC server can select the best UAV which have the appropriate parameters of task recommended by requester. So, it capable to reject to consume any offer for multiple reasons such as : the value of price, throughput, and duration (which are opposed to what the requester need). In addition, the MEC server can select another service provider to do this task. A_2 explain the loss of service provider is zero. B_2 illustrates the failure to consume the task.

- **Combination of strategies (Do not offer and Consume) :**
  - $A_3 = 0$
  - $B_3 = -I$

  In this case, the MEC server receives a demand from a requester to offer its task while the server have not the offer. It will be select the appropriate UAV that can offer this kind of tasks. A_3 illustrates the reward of UAV which will be zero when the UAV reject to offer the task (eg, it is selected to execute another task). If this is not the case, the service provider will be loss the price of task recommended by requester. B_3 reflects the failure of requester to execute its task.

- **Combination of strategies (Do not offer and Do not consume):**
  - $A_4 = 0$
  - $B_4 = 0$

  In this case, the gains of service provider and requester (A_4, B_4) are zero since both decide to neither offer nor consume the service, respectively

4.2.3 Nash's equilibrium

We use Nash's equilibrium in mixed strategy to determine the balance state of the game with taking into consideration that the service provider and requester have zero reward when changing only his own strategy.

- **Theorem:** A Nash equilibrium in pure strategy defined as: $UAV = \{(Offer, p)\}$, $R = \{(Consume, q)\}$ for service provider and requester respectively. In which the service provider chooses the Offer strategy with a probability p and the requester check Consume strategy with a probability q.

- **Evidence :** The gain of the requester in mixed strategy of service provider when use offer with the probability p and do not offer with the probability $1 - p$ defined as follows :
  - $G_R(Consume) = [B_1 * p + B_3 * (1 - p)] * q = [p * (B_1 - B_3) + B_3] * q$
  - $G_R(DoNotConsume) = [B_2 * p + B_4 * (1 - p)] * (1 - q) = 0$

  The requester select the Consume strategy when :

  $$G_R(Consume) > G_R(DoNotConsume).$$

  The gain of the service provider in mixed strategy of requester when use consume with the probability q and do not consume with the probability $1 - q$ defined as follows :

- $G_{UAV}(Offer) = [A_1 * q + A_2 * (1 - p)] * p = [q * A_1] * p$
- $G_{UAV}(DoNotOffer) = [A_3 * q + A_4 * (1 - q)] * (1 - p) = 0$

The service provider select the offer strategy when :

$$G_{UAV}(Offer) > G_{UAV}(DoNotOffer).$$

4.2.4 Examples Scenario of GTCS-MU

In our scenarios, we consider that the UAVs is already in a mission (**on path**). Thus, we propose two scenarios. In the first scenario, as shown in Figure 4.1, the user is considered as a fixed node and both service provider and user are located in the transmission range of the base station. In the second scenario (Figure 4.2), we consider the user is a mobile node and it can located outside of the transmission range of the base station, which need routing protocol to reach the nearest base station. In addition, in our scenarios, we consider a MEC server closest to base station and it can save all offers which are sended by a service provider. This offers contain various informations such as:

- The id of UAV.
- The path (source and destination) can the UAV take it.
- The price of the task.
- The energy of UAV.
- The tasks or offers that the service provider can execute (e.g:Video recording).
- The throughput and duration of the task.
- The offer live time that the service provider can provide the service.

If the MEC server have already the service with all characteristic that the user demand, so it forward the service after it deal with the end user and the payment process well done. Therefore, the database of the MEC server contains offers from various service providers. However, when a requester need to consume a specific task from a service provider, it will be send a request to the base station that contain the MEC server. The request of clients requires many informations like:

- The kind of the task recommended by a requester (e.g: video recording).
- The duration time of the task defined by a requester.
- The max price of the task (the price of the service should not exceed the max price listed by the client).
- The QoS of the task required by the requester inclusing low, medium, and high qualities.
- The path of the task or where the requester needs the service.

If the requester sends a request to the base station, this final will be transmit the request to the MEC server, then the MEC server searches the data base. If the task recommended by the requester exist, the MEC server will be send it to the requester. While if the MEC server can not find the task, it will be choose the best UAV that can provide the task with take into consideration the conditions of the requester using a GT approach.

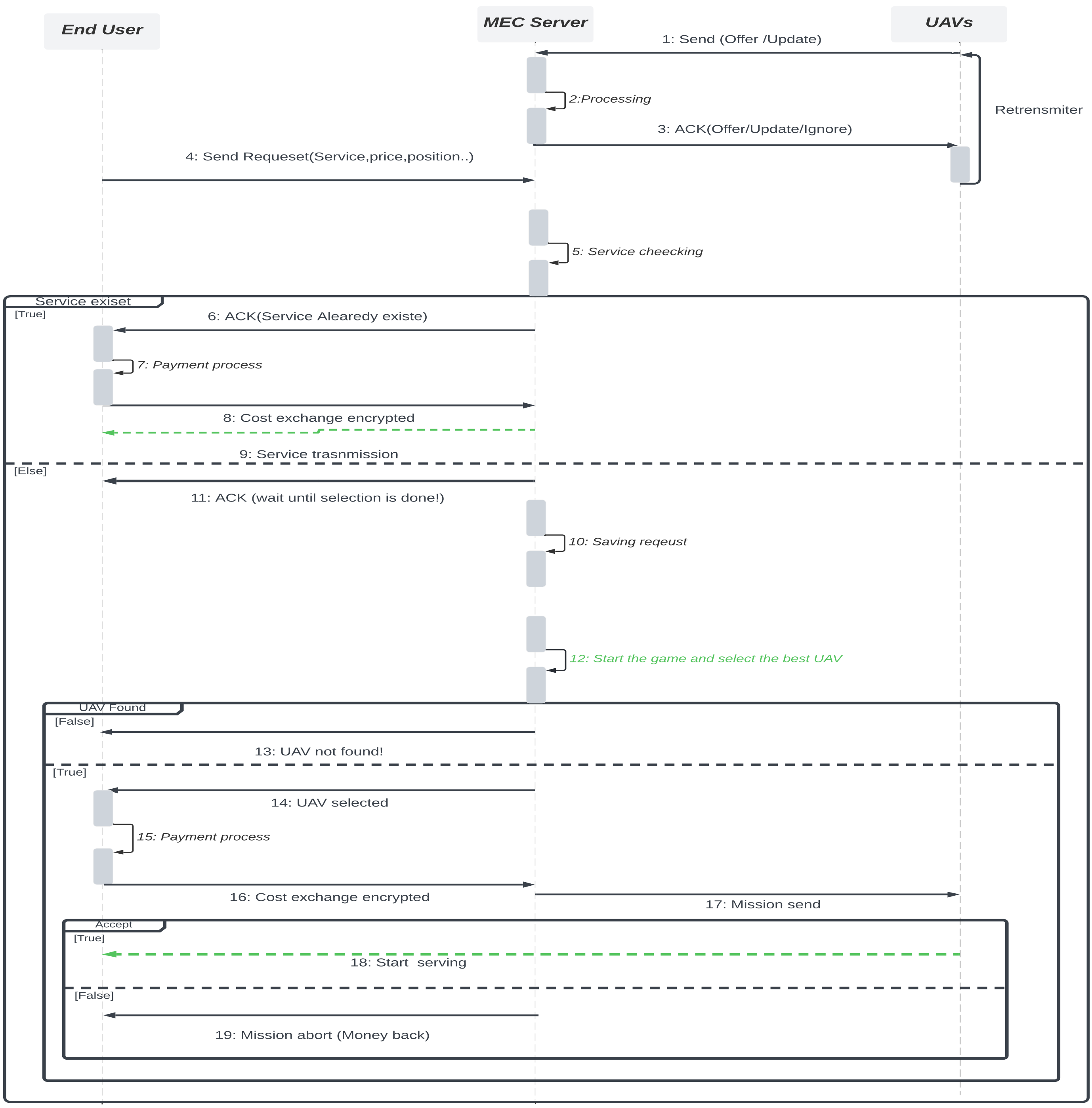


Figure 4.1: Example Scenario of GTCS-MU using Fixed User.

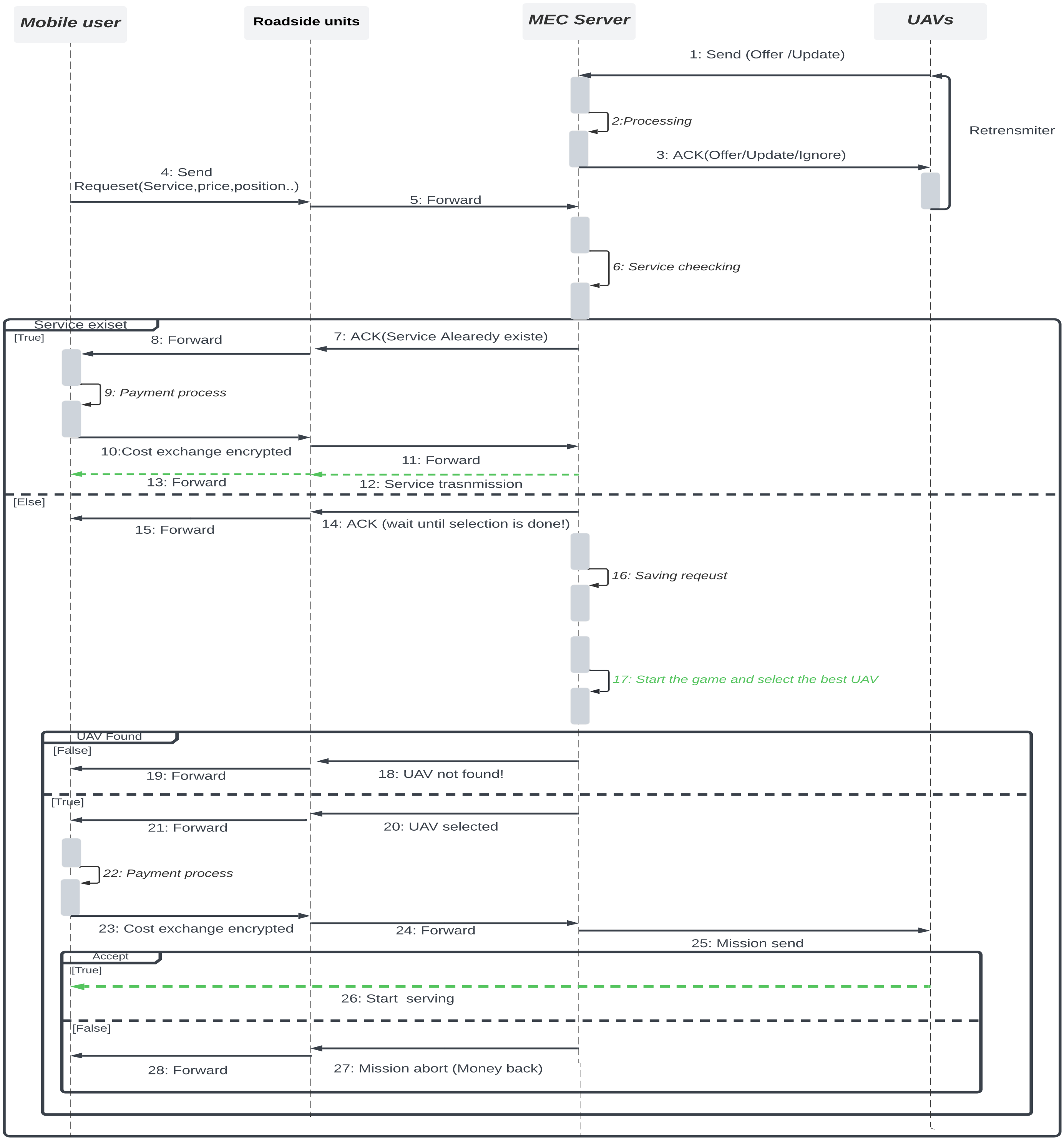


Figure 4.2: Example Scenario of GTCS-MU using Mobile User.

4.3 Performance Analysis and simulation result discussion

To evaluate our proposal performances, we used the OMNet++ [36] simulator. Mass Mobility model is used for an environment in a 1 $Km \times 1\ Km \times 100m$ area, while the transmission range of UAV is set to 300 m and the transmission range of base station is set to 600 m. The speed of UAVs varies from 30 to 50m/s. Simulation time is 200 seconds. Simulation parameters are summarized in Table 4.3.

Table 4.3: Simulation configurations

Parameter	Values
Simulator	OMNet++ (version 4.6.2)
Mobility Framework	INet (version 3.2)
Mobility model	Mass Mobility
Simulated area (m^3)	1000x1000x100
Transmission range of UAV (m)	300
Transmission range of Base Station (m)	600
Velocity (m/s)	[30-50]
Number of UAVs	10, 20, 30, 40 & 50
Simulation time (s)	200
Packet Size (bytes)	100
Routing protocol	AODV

We evaluate the following performance metrics:

- **Successful Execution Ratio :** Represents the number of successful tasks that consumed by the end user(s) in term of number of UAVs.

- **Average execution Time :** Represents the total time from sending the request to the MEC server until the reception of the last data packet.

- **Throughput :** This metric represents the total amount of data a receiver actually receives from the sender divided by the time taken by the receiver to obtain the last bit.

- **Average residual energy of the network :** Illustrate the difference between the average initial energy of the network and the average remaining energy after running all tasks. In our model, we adopt the energy formula as defined in equation 4.2.

To show the performance of our solution, we study two scenarios (one user and two users) when UAVs density is gradually increased. The number of UAVs ranges from 10 to 50. The Figure 4.3 represents the successful execution ratio. The curves show that the successful execution ratio increases when the number of UAVs increases in both two scenarios. For instance, the successful execution ratio is less then 80% where the UAVs density varies from 10 to 30.

There are two reasons for this. First, the disconnection of UAVs which may happen due to the low density of nodes with 3D mobility environment. Consequently, the number of transmitted requests is not successfully received by MEC, which decreases the successful execution ratio. Second, requesters will have more chances to find the appropriate offers in the case of high UAVs density (between 30 to 50). In addition, the curves show the successful execution ratio is inferior in the second scenario compared to the first scenario. This is due to the increasing number of collisions when the number of hops increases, especially for high UAVs density. Furthermore, the less compatibility of the second scenario requests which may have happened with the UAVs offers.

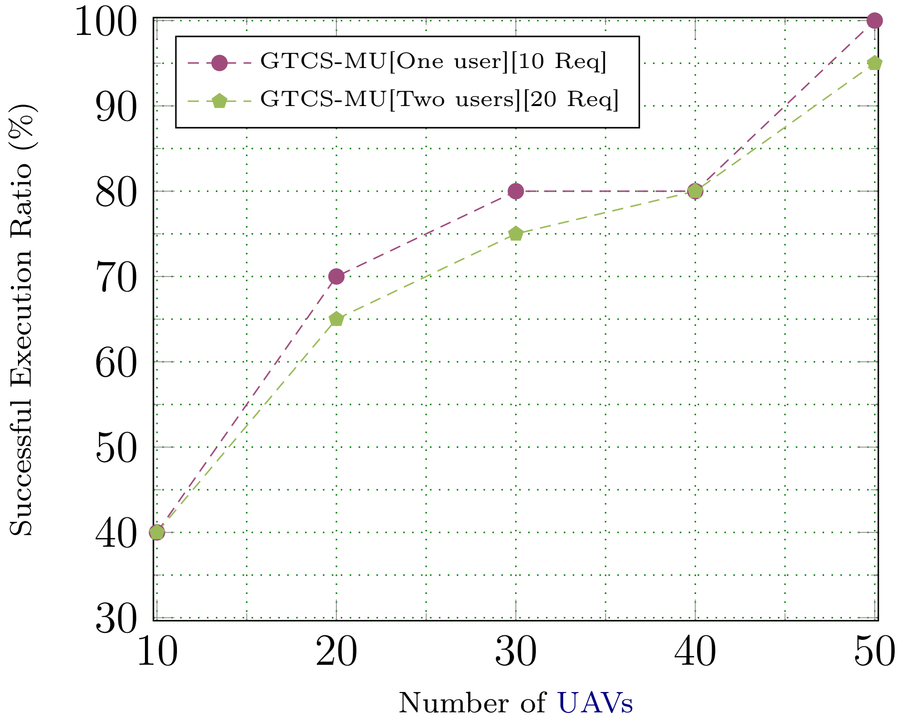


Figure 4.3: Successful Execution Ratio VS UAV density.

From Figure 4.4, it is worth noting that both two scenarios are similar while increasing UAVs density with a smaller difference between them (i.e., down to around 0.43s). In addition, the curves also depict that the average response time is increased when the density increased in both two scenarios. Because the distances between the MEC server, user(s), and UAVs require more relays in case of high density which requires more delay. Furthermore, the use of routing protocol Ad Hoc On-Demand Distance Vector (AODV) that takes time to calculate the routing table periodically.

Figure 4.5 illustrates that the second scenario utilizes better the throughput (with 15 bps higher) than the first scenario in most densities. This is because the average response time is smaller than in the second scenario (Figure 4.4) and the high number of requests in the second scenario (20 requests) compared to the first (10 requests). These two facts increase the throughput utilization in the second scenario. Figure 4.5 also depicts that the utilization of throughput is decreased when the UAVs density increases , it is due to the increase of the average response time (Figure 4.4) for both two scenarios.

Simulation results of the residual energy of network is shown in Figure 4.6. The curves present the difference between the average initial energy and the average energy after serving

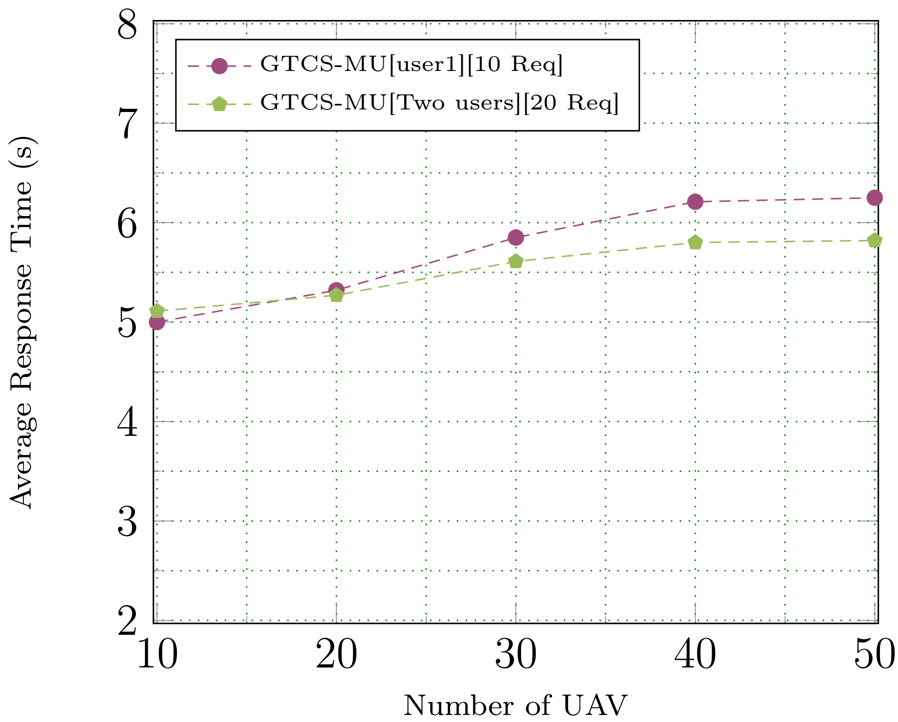


Figure 4.4: Average Execution time VS UAV density.

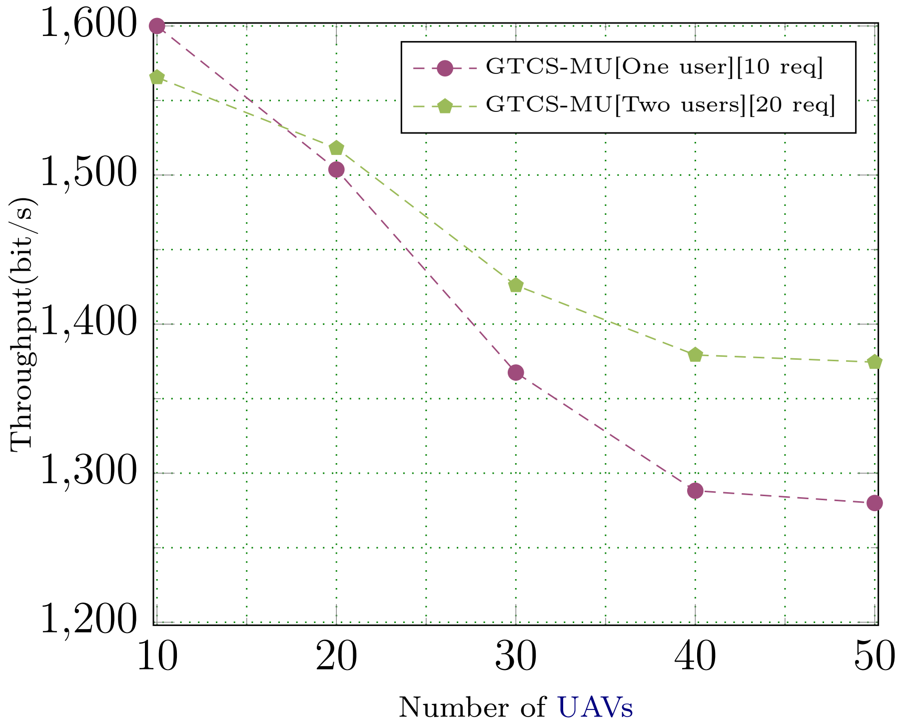


Figure 4.5: Throughput VS UAV density.

the service (energy consumption) when UAVs density is gradually increased. It is worth noting that the network energy decreased in all cases of UAVs densities. Since the requests are served, therefore, it decreases the average power, but with smaller difference (at most 14.5%). As a

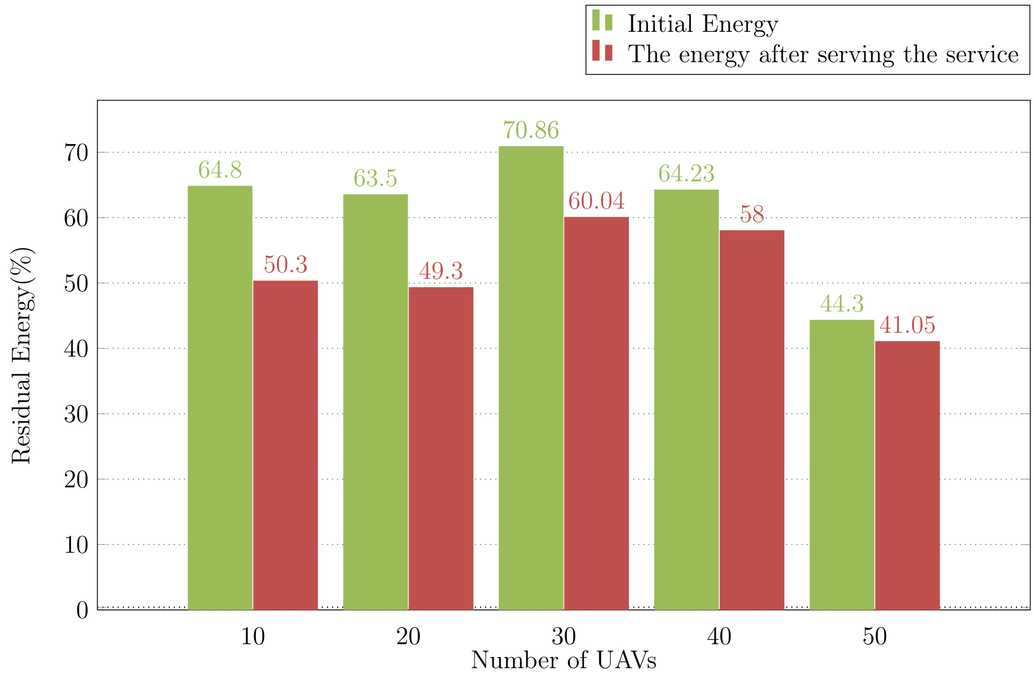


Figure 4.6: Residual Energy of Network VS UAVs density.

result, our proposal only requires lightweight energy to satisfy the services.

4.4 Conclusion

In this chapter we presented a game theory approach for cloud services in MEC and UAV enabled networks (GTCS-MU). GTCS-MU is classified as non-cooperative game-based which can taken into consideration both delay, throughput, cost, and energy. The results of the simulation conducted using OMNeT++ simulator and INET framework advocated for the efficiency performance of our method.

5

Conclusion and future perspectives

Contents

5.1 Summary of our Work

More recently, UAVs and MEC assisted networks have attracted significant research interest because of the advantages they offer. In close proximity to devices, MEC can provide instant computing applications and can improve operational services including real-time traffic monitoring, continuous sensing in vehicles, search and rescue, wildfire management, agricultural applications by decreasing the latency, increasing reliability, rapid big data processing, and throughput requirements. In this work, we studied the selection of cloud services in MEC and UAVs enabled networks. As a first step, we introduced Unmanned Aerial Vehicles (UAVs). We also presented both Cloud Computing (CC) and Edge Computing (EC). As a second step, we illustrated some related methods of services' selection with a brief showing to their advantages and drawbacks and with a detailed synthesis and comparison of all discus methods. As a third step, we presented our new selection game theoretic approach for clouds services in MEC and UAVs enabled networks.

5.2 Future Perspectives

To build on the work accomplishments, some future perspectives should be considered to design new selection approaches. One of the future work directions is to implement our second scenario by using mobile user. In addition, we plan to extend our method GTCS-MU by considering security parameters. Finally, future work will be mainly focused on the decentralization of our method by using the most suitable UAV as MEC.

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