

الجمهورية الجزائرية الديمقراطية الشعبية
PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
وزارة التعليم العالي و البحث العلمي
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
جامعة عمّار ثليجي بالأغواط
UNIVERSITY OF LAGHOUAT



FACULTY OF SCIENCES
DEPARTMENT OF COMPUTER SCIENCE

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

MEMOIRE SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
MASTER DEGREE IN COMPUTER SCIENCE

Submitted by: Aboubakeur Elseddik Rezigat & Hadj Saad Benguettache

THEME

Selection of Services in UAV Clouds

Jury members:

<i>Ms</i>	Zohra Abdelhafidi	MC(A)	(University of Laghouat)	President
<i>Mr</i>	Chaker Abdelaziz Kerrache	MC(B)	(University of Ghardaia)	Examiner
<i>Ms</i>	Fatima Zohra Bousbaa	MC(B)	(University of Laghouat)	Advisor

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République Algérienne Démocratique et Populaire
وزارة التعليم العالي و البحث العلمي
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
جامعة عمّار ثليجي بالأغواط
UNIVERSITÉ AMAR TELIDJI LAGHOUAT



FACULTE DES SCIENCES
DEPARTEMENT D'INFORMATIQUE

Domaine : Mathématiques et Informatique
Filière : Informatique
Option : Réseaux, systèmes, et application distribuées

Mémoire de Master

Présenté par : Aboubakeur Elseddik Rezigat & Hadj Saad Benguettache

THÈME

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Soutenu publiquement devant le jury composé de :

<i>M^{lle}</i>	Zohra Abdelhafidi	MC(A)	(University of Laghouat)	Président
<i>Mr</i>	Chaker Abdelaziz Kerrache	MC(B)	(Université de Ghardaia)	Examineur
<i>M^{lle}</i>	Fatima Zohra Bousbaa	MC(B)	(Université de Laghouat)	Encadreur

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Acknowledgments

First off, all praise and gratitude is due to Allah, for giving us the strength and the will to do this modest work.

We would like to thank our advisor Dr. Fatima Zohra Bousbaa for her advice, guidance and unwavering support through the duration of our project.

We would like to show our sincere appreciation to the committee members, Dr Zohra Abdelhafidi and Dr. Chaker Abdelaziz Kerrache, we thank them for taking the time to consult our humble work, and we are looking forward to hear from them and consider their constructive critics and valuable advice to improve it.

Finally, we would like to express our deep gratitude to our families who have always supported us and to all who participated in carrying out this dissertation. As well as all of the teachers who contributed to our training.

Sedik & Saad, October 2020

Dedications

I dedicate this modest work to the two most amazing families a man could ever ask for, who have never ceased to sacrifice and support so that I can succeed.

To my dear mother Zrouga and my father Amar who supported me during all my years of studies, may God keep them.

To my dear sisters Achwak, Samah, Olaya, Khouloud and little Siham.

To all the members of my family who have helped me during all My studies.

To all my dear friends Especially Saad, Idris, Yacine ...

And to all who have taught me throughout my school life.

To my Master2 classmates in general.

Thanks everyone.

.....

REZIGAT Aboubakeur El-Seddik .

Dedications

I dedicate this modest work to the two most amazing families a man could ever ask for, who have never ceased to sacrifice and support so that I can succeed.

To my dear mother Metiha and my father Abdelkader who supported me during all my years of studies, may God keep them.

To my dear brothers Amar and Ismail and my sister Amel.

To all the members of my family who have helped me during all My studies.

To all my dear friends Especially Sedik, Idris, Yacine ...

And to all who have taught me throughout my school life.

To my Master2 classmates in general.

Thanks everyone.

.....

BENGUETTACHE Hadj Saad .

Abstract

Nowadays, [Unmanned Aerial Vehicles \(UAVs\)](#) cloud have attracted wide attentions from both industrial and academic communities as a new paradigm offering flexible services. This new concept utilizes the recent technologies of mobile cloud computing. The collaboration between these technologies represents a fantastic vision of the future, where everything is connected to the Internet, thereby offering intelligent services and facilitating decision-making between cooperative [UAVs](#).

In this work, we study the new [Unmanned Aerial Vehicle \(UAV\)](#) clouds computing technology. Our objectives are to (1) provide a detailed review of the existing services' selection methods and to (2) propose a new [Game Theoretic approach for Services' Selection in UAV Clouds \(GTSS-UC\)](#) aiming to enable normal users to select 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 is based on the [Game Theory \(GT\)](#) method and takes into account the user requirements and the [UAVs](#) provider qualities to find the most adequate provider. The results of the simulation conducted using NS-2 simulator advocate for the efficiency of our method.

Keywords : UAVs, Cloud Computing, Services' Selection, Game Theory Method.

Résumé

De nos jours, le cloud véhiculaire aérien sans pilote (**UAVs**) a attiré une large attention de la communauté industrielle et universitaire en tant que nouveau paradigme en raison de ses services flexibles. Ce nouveau concept utilise les technologies récentes du cloud mobile. La collaboration entre ces technologies représente une vision fantastique du futur, dans laquelle tout est connecté à Internet afin de simplifier l'offre et la sélection des services intelligents et de faciliter la prise de décision entre drones coopératifs.

Dans ce travail, nous étudions une nouvelle technologie de cloud computing des drones. Notre objectif est (1) de présenter des méthodes existantes de sélection des services et (2) de proposer une nouvelle solution basée sur la théorie des jeux pour la sélection des services dans le cloud des drones (**GTSS-UC**) qui permet aux utilisateurs de sélectionner le fournisseur de services le plus adéquat. Étant donné que chaque fournisseur de services 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 prend en compte les besoins des utilisateurs et les qualités du fournisseur afin de trouver le fournisseur le plus adéquat.

Mots clés: : UAVs, Cloud Computing, Sélection de Services, Théorie des Jeux

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LIST OF ACRONYMS

4G Fourth Generation. 16

CC Cloud Computing. 9, 10, 11, 12, 15

CH Cloud Hosting. 10

DAS Delay Aware Selection. 17

DBaaS DataBase as a Service. 11

DCCSVC Discovering and Consuming Cloud Services in Vehicular Cloud. 15, 16

EAS Energy Aware Selection. 17

FaaS Functions as a Service. 11

FANET Flying Ad hoc NETWORK. 1, 4

GBS Ground Base Station. 4, 7, 8

GSN Ground Sensor Nodes. 5

GT Game Theory. v, vi, 2, 23, 25

GTSS-UC Game Theoretic approach for Services' Selection in UAV Clouds. v, vi, viii, 2, 22, 30, 35

HAUs High Altitude UAVs. 4

HWH Hybrid Web Hosting. 10

- IaaS** Infrastructure as a Service. 11
- IoT** Internet of things. 5
- IT** Information Technology. 9, 11
- LAUs** Low Altitude UAVs. 4
- LIP** Linear Integer Problem. 17, 20
- LoS** Line-of-Sight. 8
- LTE-A** Long Term Evolution- Advanced. 16
- MANET** Mobile Ad-hoc NETWORKs. 14
- MAUs** Medium Altitude UAVs. 4
- MBaaS** Mobile Back-end as a Service. 11
- MCC** Mobile Cloud Computing. 11, 12, 15
- NIST** National Institute of Standards and Technology. 9
- PaaS** Platform as a Service. 11
- PCI** Payment card industry. 10
- QoS** Quality of Service. 14, 15, 21
- RCS-VC** Renting out and Consuming Services in Vehicular Cloud. 15, 16, 17
- SaaS** Software as a Service. 11
- SATCOM** Satellite Communication. 7, 8
- SO** System Orchestrator. 18
- U2G** UAV-to-Ground. 7
- U2U** UAV-to-UAV. 4, 7, 8
- UAV** Unmanned Aerial Vehicle. v, vii, ix, x, 1, 2, 3, 4, 5, 6, 7, 12, 13, 14, 17, 18, 19, 20, 21, 22, 26, 27, 30, 31, 34, 35

UAVs Unmanned Aerial Vehicles. v, vi, ix, 1, 2, 3, 4, 5, 6, 7, 8, 12, 17, 18, 19, 20, 21, 26, 32, 33, 34, 35

VANET Vehicular Ad-hoc NETWORKs. 14, 15, 16

CHAPTER 1

INTRODUCTION

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1.1 Context

In the recent past, with the technological advancement of wireless communication and the increasing use of cloud computing, users can get many services. In addition, with the new technology of Unmanned Aerial Vehicles (UAVs), owing to their autonomy, flexibility, and broad range of application domains, UAVs have been considered as enablers of various applications that include military, surveillance and monitoring, telecommunications, managing wildfire, delivery of medical supplies, rescue operations and many other tasks [2, 3, 4, 5, 6, 7, 8].

In order to successfully achieve a service in an efficient manner, UAV clouds utilizes the recent technology of mobile cloud computing, which represents a set of UAVs cooperatively organized as a new type of network called Flying Ad hoc NETWORK (FANET), which provides rapid deployment and the ability to fly above any obstacle. However, it also poses many challenges in selecting the most suitable service such as, energy consumption and the time required to execute the task.

1.2 Problem Statement and Motivations

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, namely how to create the communication platform between UAVs and how to select the most suitable UAV service provider, given that every service provider is characterized by specific features. Therefore, we attempt to design a new efficient method for services' selection that gives the client the ability to choose the appropriate service provider for their needs.

1.3 Organization of the Memoire

This work is organized as follows:

- **Chapter 2** introduces UAVs, Cloud Computing and gives an overview of UAV Clouds and presents some challenges that face them.
- **Chapter 3** concerns the state-of-the-art in which we illustrate different methods in services' selection mobile, vehicular, and UAV Clouds with a detailed description and comparison of all discussed protocols.
- **Chapter 4** concerns the presentation of our new method (GTSS-UC). First, we start by giving an introduction of Game Theory (GT), then we describe our method's implementation along with giving an example to further clarify it's steps.
- Finally, we will finish by giving a general conclusion summarizing this work and the possible routes that we could take in furthering its development in the future.

CHAPTER 2

UAV CLOUDS: BACKGROUND

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2.1 Introduction

Unmanned aerial vehicles (UAVs) have been the subject of concerted research over the past few years, owing to their flexibility, autonomy, ease of installation, relatively small operating expenses, and wide range of application domains, Indeed UAVs have been considered as enablers of various civilian and military applications, such as surveillance and monitoring, managing wildfire, agricultural applications, delivery of medical supplies, and rescue operations.

Along this chapter, we start with the definition of **UAVs**, their classification, applications and their communication architecture then we define cloud computing, list the different types of cloud and the the common cloud service models. We also give an overview of **UAV Clouds** and how that notion came to be, in addition to that we present some challenges that face it.

2.2 Unmanned Aerial Vehicles

Unmanned aerial vehicle **UAV**, commonly known as 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 [9] [10]. To improve the performance of **UAVs** on their missions, researches are conducted to make **UAVs** cooperative in a controlled way by a control station or autonomously.

2.2.1 Classification

As depicted in Figure 3.3, **UAVs** in **FANET** are naturally classified based on their altitudes, into **High Altitude UAVs (HAUs)**, Medium altitude **UAVs (Medium Altitude UAVs (MAUs))**, and Low altitude **UAVs (Low Altitude UAVs (LAUs))**.

- **HAUs** have altitudes above 20 km and they are almost stationary, such as satellites, airship, and hot air balloon.
- **MAUs** at medium altitudes up to 11 km, such as aircraft, and they move more quickly from the point of view of ground nodes.
- **LAUs** their altitudes reach few kilometers and are highly mobile, such as drones or copters.

Traditionally, **FANET** is generally managed by a control station, such as a **Ground Base Station (GBS)** or a satellite, which are used for communication and to share critical information. There are some particular **UAVs** that are designated according to several features to communicate with ground stations, ground mobile nodes (e.g., vehicles or ships), and satellites, thus achieving **UAV-to-UAV (U2U)** communications via the infrastructure [11].

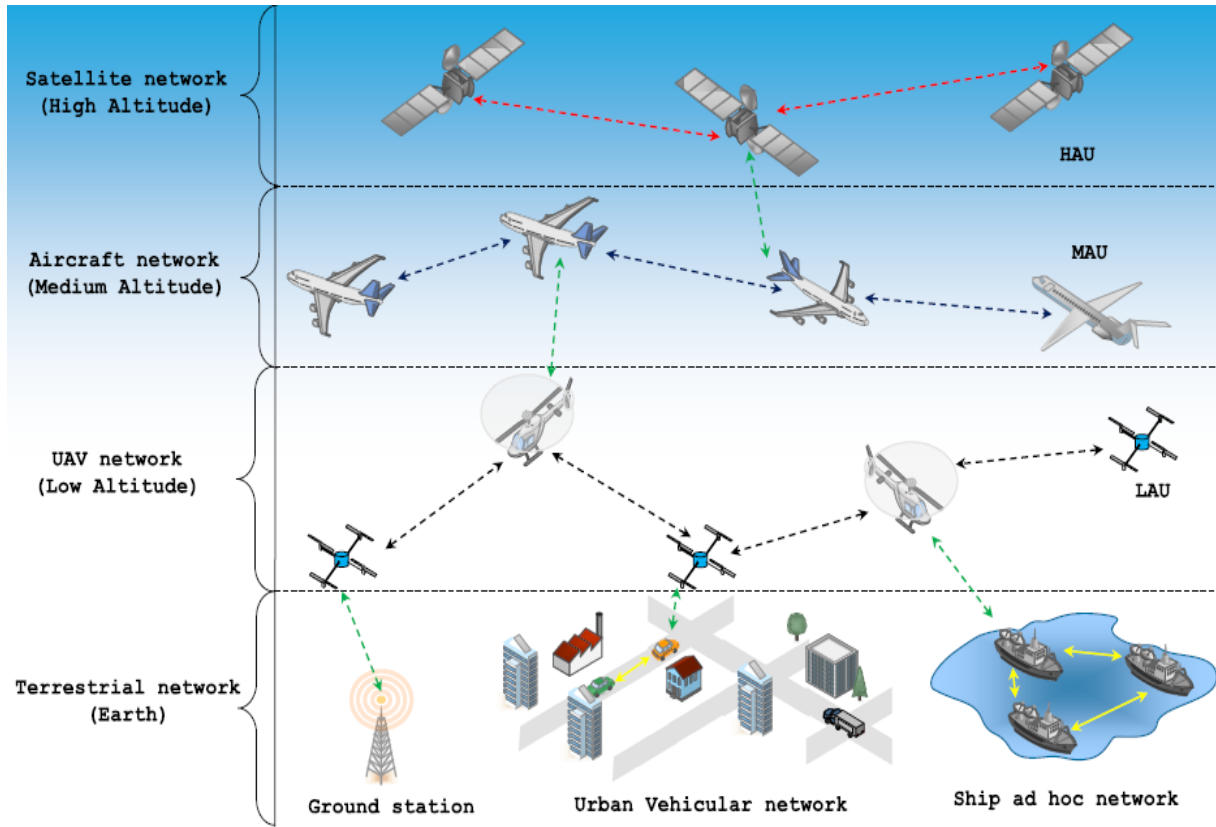


Figure 2.1: UAVs altitude-based classification.

2.2.2 Applications

The technological advancement in the capabilities of UAV enables their use for different purposes in the sector of unmanned operations. The application scenarios that can benefit from UAV technologies are diverse such as Search and Rescue Operations, Security, Monitoring, and Surveillance, Agricultural Applications [2, 3, 4, 5, 6, 7, 8]. In this section, we introduce a brief overview of some services that UAVs can provide.

- **Informations Gathering:** UAV is considered as a mobile sensor able to gather information and collect useful data via its different sensors from external resources and entities. These external resources can be Ground Sensor Nodes (GSN), vehicles, Internet of things (IoT) devices or any object connected to the cloud. Then, collected data can be offered as a service to the users and other UAVs.
- **Film and Photography:** Aerial film and photography service providers are probably the heaviest commercial users of unmanned aerial systems more recently. The technical requirement is comparatively low in many cases, off-the-shelf cameras are attached to

the UAV with ready-made or makeshift mountings (c.f. Fig. 2.2). For a better focus and improved results, the camera and the UAV can be handled by different operators. Significant cost savings can be achieved, and this results in a shift from more expensive options to UAVs, and opens up new customer segments. Film/photo missions that would previously have used a helicopter can be executed at a fraction of the cost. In some instances, the UAV replaces expensive technology that is not even a flying device. For example, instead of using computer technology to create scenes, these can be filmed by UAV.



Figure 2.2: UAV loaded with camera.

- **Agriculture and Forestry:** Probably the agriculture and forestry industries don't spring to mind when considering potential applications for unmanned aerial systems. But in precision agriculture, UAVs are already playing a vital role (Fig. 2.3). They allow farmers to gather real-time data on crops, detect irregularities as early as possible, and take better decisions about using fertilizers, herbicides, and pesticides. In addition, animal tracking is another task well suited to the capabilities of UAVs.



Figure 2.3: Agriculture services via UAV.

- **Delivering Services:** UAVs have the potential to carry small items quickly from one place to another without having to worry about traffic (c.f. Fig. 2.4), this can make them helpful specially for search and rescue cases such as delivering packages, goods, food packets, medical supplies, life jackets,...etc.



Figure 2.4: Delivering services via UAV.

2.2.3 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 three types of communication:

(i) UAV-to-UAV U2U, (ii) UAV-to-Ground (U2G), and (iii) Satellite Communication (SATCOM) [11, 12], as shown in Fig. 2.5.

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 phenomena.
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).

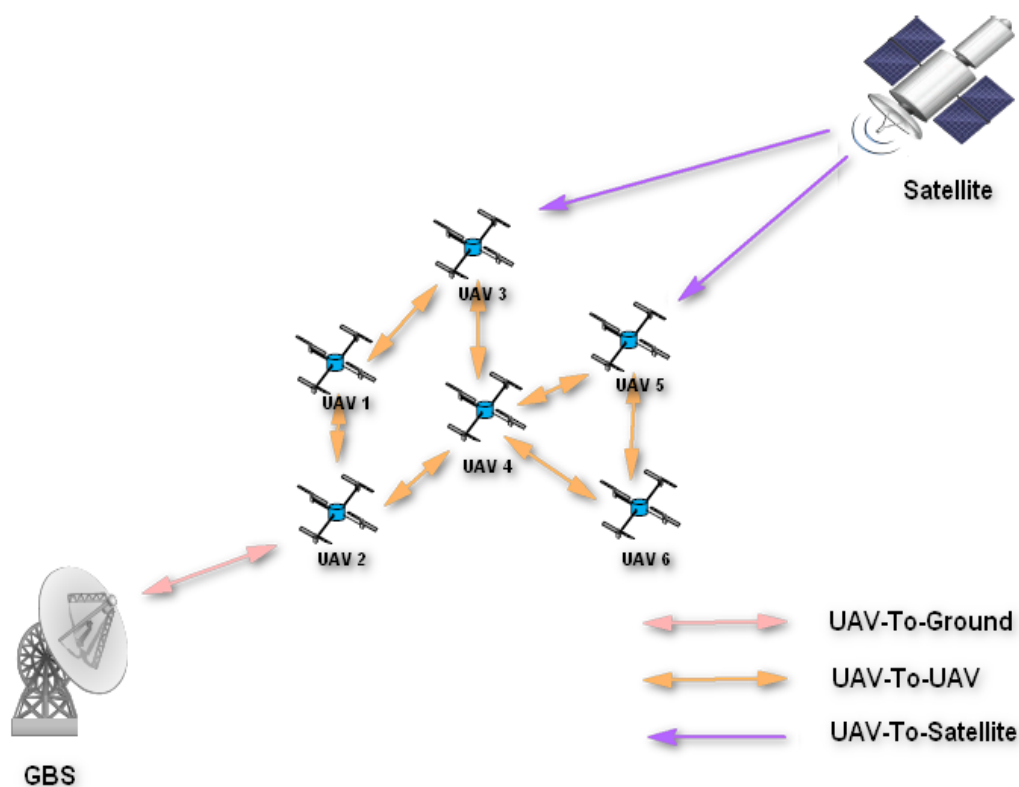


Figure 2.5: UAVs communication.

2.3 Cloud Computing

There exist a number of proposed definitions for **Cloud Computing (CC)**, although the most widely agreed upon seems be that put forth by the **National Institute of Standards and Technology (NIST)**. Indeed, the **NIST** has defined **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" [13].

CC has emerged as a popular solution to provide cheap and easy access to externalized **Information Technology (IT)** organizations (e.g., research centers, enterprises) benefit from **CC** to host their applications. Through virtualization, **CC** is able to address with the same physical infrastructure a large client base with different computational needs [14] [15]. In contrast to previous paradigms (Clusters and Grid computing), **CC** is not application-oriented but service-oriented, it offers on demand virtualized resources as measurable and billable utilities [16].

2.3.1 Types of Clouds

According to the study in [17], clouds can be classified into four types: (i) public cloud, (ii) community cloud, (iii) hybrid cloud, and (iv) private cloud.

1. **Public Cloud:** Public cloud or external cloud describes **CC** in the traditional mainstream sense, whereby resources are dynamically provisioned on a fine-grained, self-service basis over the Internet, via web applications/web services, from an off-site third-party provider who provides and allocates their resources to the regular users and bills on a fine-grained utility computing basis.
2. **Community Cloud:** A community cloud may be established where several organizations have similar requirements and look for to share infrastructure so as to realize some of the benefits of **CC**. With the costs spread over fewer users than a public cloud (but more than a single tenant) this option is more expensive but may offer a higher level of privacy, security and/or policy compliance. Examples of community cloud include Google's "Gov Cloud".
3. **Hybrid Cloud:** A hybrid cloud environment consisting of multiple internal and/or external providers will be typical for most enterprises. By integrating multiple cloud services users may be able to ease the transition to public cloud services while avoiding issues such as **Payment card industry (PCI)** compliance. Another perspective on deploying a web application in the cloud is using **Hybrid Web Hosting (HWH)**, where the hosting infrastructure is a mix between **Cloud Hosting (CH)** for the web server, and Managed dedicated server for the database server.
4. **Private Cloud:** Private cloud is a type of cloud computing that delivers similar advantages to public cloud, including scalability and self-service, but through a proprietary architecture. Unlike public clouds, which deliver services to multiple organizations, a private cloud is dedicated to the needs and goals of a single organization.

Private cloud and internal cloud have been described as neologisms, however the concepts itself pre-dates the term cloud by 40 years. Even within modern utility industries, hybrid models still exist despite the formation of reasonably well functioning markets and the ability to combine multiple providers.

2.3.2 Common Cloud Service Models

1. **Software as a Service (SaaS)**: SaaS is a software delivery method that provides access to software and its functions remotely as a Web-based service. Instead of paying an upfront fee to purchase and/or license software, SaaS customers pay a recurring (often monthly or annual) fee to subscribe to the service. In general, they can access the SaaS from any Internet-connected device, any time day or night. Well-known examples of SaaS include Salesforce.com, Microsoft Office 365, Google G Suite, Dropbox, Adobe Creative Cloud and others [18].
2. **Platform as a Service (PaaS)**: PaaS is a computing platform delivered as a service. Here the platform is outsourced to a company or data center instead of them purchasing and managing their own hardware and software layers. Most PaaSes are designed for developers and aim to simplify the process of creating and deploying software. For example, a Web developer might use a PaaS that includes operating system software, Web server software, a database and related Web development tools. The leading PaaS vendors include Amazon Web Services, Microsoft Azure and Google Cloud Platform [18].
3. **Infrastructure as a Service (IaaS)**: Computer infrastructure, such as servers, storage and networking delivered as a service. IaaS is popular with enterprises that appreciate the convenience of having the cloud vendor manage their IT infrastructure. They also sometimes see cost savings as a result of paying only for the computing resources they use. The leading IaaS vendors include Amazon Web Services, Microsoft Azure and Google Cloud Platform [18].
4. While SaaS, PaaS and IaaS are the three most common types of cloud services, CC vendors sometimes also use other "as a service" labels to describe their offerings. For example, some offer DataBase as a Service (DBaaS), Mobile Back-end as a Service (MBaaS), Functions as a Service (FaaS) and many others.

2.4 Services' Selection in UAV Clouds

Undeniably, Internet technology has grown exponentially since its inception. CC reflects the exploitation of the hardware and software resources of remote computer servers across a network, usually the Internet [19]. These servers are rented on demand, most often by usage band according to quality criteria (power, storage capacity, bandwidth, ...etc).

With the emergence of mobile applications, Mobile Cloud Computing (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 mobile devices such as smartphones and tablets [20].

In addition, UAV Clouds represents a particular class of MCC which combines the concept of CC and UAVs. It allows each UAV with its equipments (sensors, cameras, ...) to offer and lease these resources as a service to clients, and thus to act as a mobile cloud server [21]. 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 from clients to achieve it. And each service provider has a specific characteristics (such as cost and time of execution). In this case we need to a service selection method to select the most suitable service provider for normal users.

2.5 Challenges

Since different UAVs belonging to different entity providers can offer the same service, a critical question should be addressed, and it is the question of *how to select the best Provider fitting the requirements of the UAV's service Consumer in terms of Cost, duration of execution and the energy consumption in UAVs?*

- **Execution Cost:** Each service provider propose their service along with advertising the cost and the clients prefer the services with the lowest cost , the problem is how to select the service provider that has the minimal cost of execution.
- **Duration of Execution:** In reality, some requests need to be achieved in a short time, so here we talk about how to select the service provider having the best expected delay meaning the least possible delay between the moment of sending the request and receiving data service.
- **Energy Consumption:** While the UAV handles the task it need to go to the position of the event, then process the event with the required sensors and transmit the data to the client. all these operation need energy and the question is how to select the service provider that has the required energy to handle the event.

2.6 Conclusion

This chapter introduced the basic concepts behind the UAV clouds, such as types, challenges, and services' selection. The next chapter will present and analyze the existing services' selection methods in UAV clouds.

CHAPTER 3

SERVICES' SELECTION IN UAV CLOUDS: RELATED WORK

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3.1 Introduction

In UAV Clouds, there are critical **Quality of Service (QoS)** parameters to be taken into account when processing a service request by a service provider. For instance, 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 this chapter, we will present some methods of service selection in mobile and vehicular cloud adding to that the existing method in UAV clouds.

3.2 Services' selection: Related work

In the research literature, many service selection methods are presented in [Mobile Ad-hoc NETWORKS \(MANET\)](#) [22, 23] and [Vehicular Ad-hoc NETWORKS \(VANET\)](#) [24, 25, 26, 27, 28]. However, services' selection are poorly studied in [UAV](#) clouds. To the best of our knowledge, only a one work can be found in the related literature addressing the services' selection in [UAV](#) clouds [1].

3.2.1 Services' selection in mobile and vehicular cloud

As a specific class of Cloud Computing (CC), the Mobile Cloud Computing (MCC) combines CC and wireless networks such as 4G and Wi-Fi [29]. Proposed works in this context address the challenge of how the mobile users can efficiently make use of cloud service by optimizing the resource utilization and their QoS [22, 23].

In addition, traditional Vehicular Ad-hoc NETWORKS (VANET) have been combined with the CC giving birth to the Vehicular Cloud paradigm [30]. In this context, many strategies of services' selection are presented [24, 25, 26, 27, 28]. For instance, Brik et al. proposed two protocols for providing and consuming services, [Discovering and Consuming Cloud Services in Vehicular Cloud \(DCCSVC\)](#) [27] and [Renting out and Consuming Services in Vehicular Cloud \(RCS-VC\)](#) [28].

(i) The DCCSVC protocol [27] primarily relies on public buses which act as cloud directories forming a dynamic index for consumer and supplier vehicles. Public buses have been chosen to use as repertoires for the following two reasons:

- Their predictability in time and space in the urban environment.
- They cover most of the urban areas and therefore they improve the connectivity of the network.

Moreover, authors of DCCSVC propose a new grid-based localization technique to track the provider vehicles' movement, which is based also on public buses. For this, DCCSVC partitioned the predetermined path of each group of buses into several cells. Every cell has a unique cell identity. The cells are grouped into Tracking Bus Path (TBP) and every TBP has a unique TBP Identity (TBPI). Then, when a Provider Vehicle (PV) registers a service at a public bus, it will be informed by the corresponding TBPI. In other words, it will be informed by all cells covered by this bus. If this PV moves out this TBP, it must register again at the nearest bus and receive a new TBPI. Fig. 3.1 shows a general overview of the environment in which DCCSVC Protocol operates.

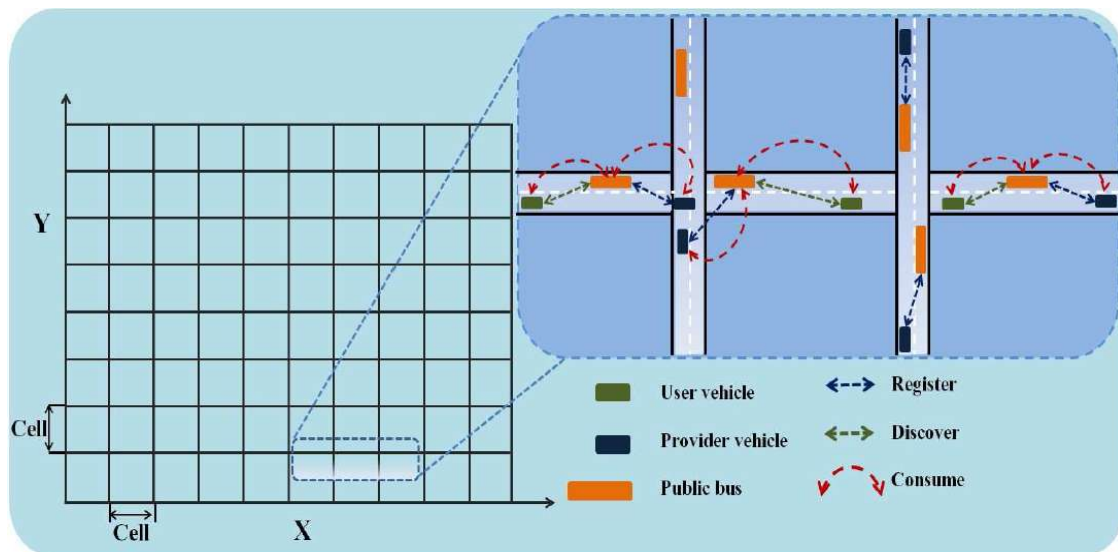


Figure 3.1: A general view of DCCS-VC.

- **Service selection in DCCSVC:**

DCCSVC is based on fuzzy logic method to allow each public bus to select the most suitable supplier vehicle in DCCSVC protocol, instead of sending consumers a list of all supplier vehicles [31].

- (ii) The RCS-VC protocol [28] enables user vehicles to discover provider vehicles of desired services and consume their services. RCS-VC extends the infrastructure of the Fourth Generation (4G) Long Term Evolution- Advanced (LTE-A) network to exploit it as cloud directories with which provider vehicles register, and from which consumer vehicles discover all offered services. To this end, RCS-VC adds a new server namely Vehicular Services Directory (VSD) to store information about providers and serve as dynamic index of such providers. To track providers' movement and deal with the high mobility challenge in VANET, RCS-VC chooses to connect the VSD server to the Mobility Management Entity (MME) which is responsible for the mobility management. Fig.2 shows a general overview of the environment in which RCS-VC protocol operates.

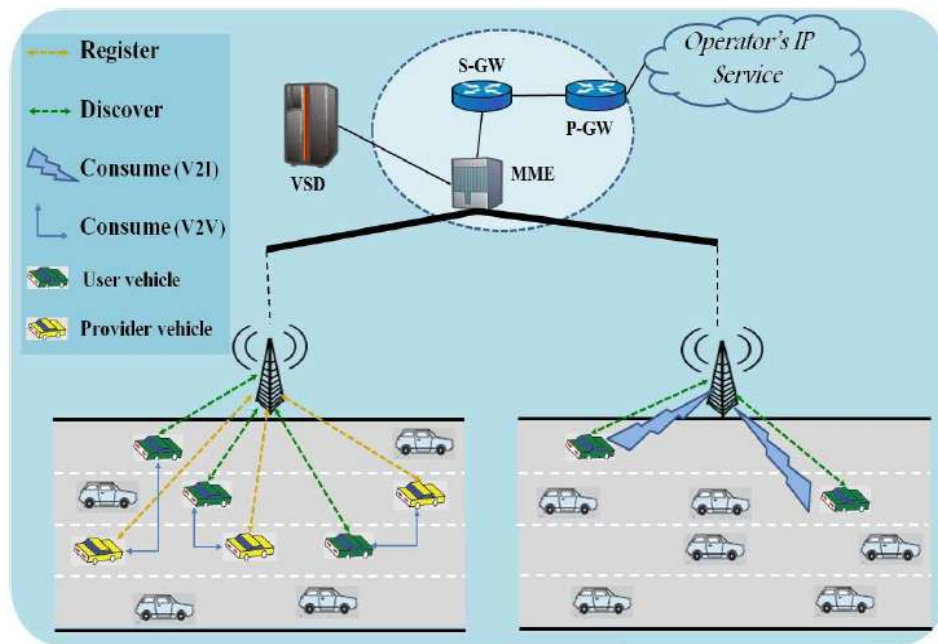


Figure 3.2: A general view of RCS-VC.

- **Service selection in RCS-VC :**

RCS-VC is based on game theory approach for service selection in Vehicular Cloud, which is a generic model that allows consumer vehicles to select the best suppliers on the road.

3.2.2 Services' Selection in UAV clouds

In UAVs clouds, one of the major problems is to select the appropriate UAVs. This selection may be based on different criteria, such as UAVs equipment, energy budget, geographical proximity of the UAV to the area of interest,... etc. For the selection mechanism, only a one method can be found in the related literature addressing the services' selection in UAV clouds [1]. Motlagh et al. proposed and formulated two Linear Integer Problem (LIP) optimization solutions by aiming at minimizing the energy consumption of UAV (Energy Aware Selection (EAS)) and shortening the UAVs operation time (Delay Aware Selection (DAS)).

1. **UAV selection :** The initial consideration for selecting a UAV to do a specific task is subject to the equipment required by the task/event. Accordingly, the UAV residual energy amount and the energy requirement of the task. Moreover, the distance to the event location, the UAV speed, the time needed to travel and complete a task, all need

to be well investigated by developing optimized algorithms and computations in order to find an optimal solution for the best UAV selection. Another consideration is that a UAV selection is application-intended based, the type of application directly will affect the selection of the UAV. This is because the application specifies the type of required sensor(s), camera(s) or device(s) onboard.

- 2. Selection mechanism:** For UAV selection mechanism, Let u denote to a UAV, N be a set of UAVs in the network, E denote to an event and $u \in N$ i.e. u be a UAV in N . For exemple, there is five UAVs are flying and each one carries specific equipment onboard which pointed by different colors and shapes in Figure 3.3. Once an event occurs and System Orchestrator (SO) receives a request for a UAV which should have Laser Scanner, Low Visibility Camera and Thermal Infrared Sensor. The SO should select a UAV or set of UAVs that has the required equipment onboard. The information from the Figure 3.3 shows that the possible solution to this should be a combination of these UAVs. This combination produces three sets of UAVs as $\{u_1, u_5\}$, $\{u_2, u_5\}$, and $\{u_2, u_4\}$ where u stands for UAV. After constructing the possible sets of UAVs, the best set should be chosen. The requirement of the best set selection is based on the computing the overall required time and energy to accomplish the task. The optimal set of the UAVs will be the one that needs minimum amount of time and consumes the lowest amount of energy in order to accomplish and complete the task requested by the event.

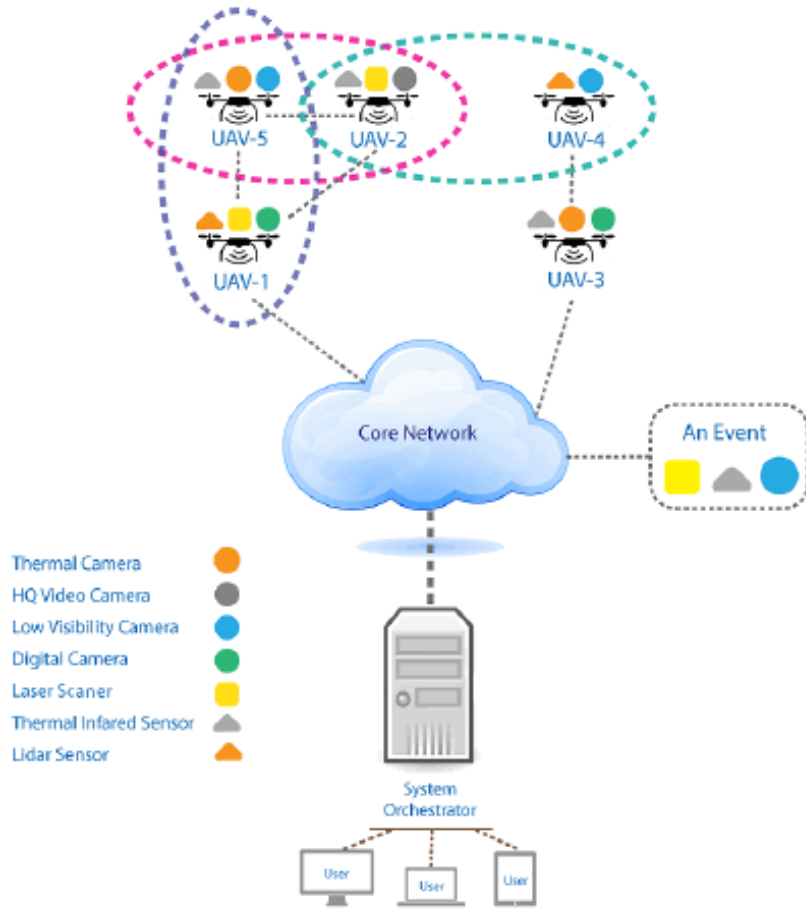


Figure 3.3: UAVs selection mechanisms [1].

3. **Optimal solutions for UAV selection:** The selection is based on the computing the overall required time and energy to accomplish the task. The total time of the UAV operation τ_u^{ToT} depends on the travel time of UAV to the event location, sensing and processing and data transmission times:

$$\tau_u^{ToT} = \tau_u^{Travel} + \tau_u^{SenseProcess} + \tau_u^{Transmit}$$

The total needed energy for task completion ε_u^{ToT} is computed based on the amount of the energy required for the travel, sensing/processing and the transmission energies:

$$\varepsilon_u^{ToT} = \varepsilon_u^{Travel} + \varepsilon_u^{SenseProcess} + \varepsilon_u^{Transmit}$$

Before starting the selection process, the eligible UAVs \dot{N} should be selected and they must satisfy the following conditions :

- Power constraint : $\varepsilon_u^{Battery} > \varepsilon_u^{ToT}$
- Equipment constraint : defined by the following conditions :
 - UAV reaches the altitude of event : $maxH_u \geq Z_E$
 - UAV has the required sensors to handle the event : $S_u \cap S_E \neq \emptyset$

(a) **Optimization of energy consumption :**

Let χ_u be a boolean decision variable that represents if a UAV $u \in \ddot{N}$ should be selected to handle the event E .

$$\chi_u = \begin{cases} 1 & \text{If } u \text{ is selected to handle the event } E \\ 0 & \text{Otherwise} \end{cases}$$

This solution aims to minimize as much as possible the energy consumption by selecting the minimum number of UAVs in the network while the time delay do not exceed a predefined threshold τ_{th} . This solution is formulated through the following Linear Integer Problem (LIP):

$$\begin{cases} Min \sum \varepsilon_u^{ToT} \cdot \chi_u \\ \forall s \in S_E : \sum_{u \in \ddot{N} \wedge s \in S_E} \chi_u \geq 1 \\ \forall u \in \ddot{N} : \tau_u^{ToT} \cdot \chi_u \leq \tau_{th} \\ \forall u \in \ddot{N} : \chi_u \in \{0, 1\} \end{cases} \quad (3.1)$$

Where :

- 1st constraint : The selected UAVs have the required sensors to deal with the event E .
- 2nd constraint : The time latency of each selected UAV should not exceed the threshold τ_{th} .
- 3rd constraint : χ_u is a boolean decision variable.

(b) **Optimization of operation time:**

Let χ_u be a boolean decision variable that represents if a UAV $u \in \ddot{N}$ should be selected to handle the event E .

$$\chi_u = \begin{cases} 1 & \text{If } u \text{ is selected to handle the event } E \\ 0 & \text{Otherwise} \end{cases}$$

This solution aims to minimize as much as possible the time response of UAVs while the residual energy of these UAVs should exceed a predefined threshold ε_{th} .

This solution is formulated through the following Linear Integer Problem (LIP):

$$\left\{ \begin{array}{l} \text{Min} \tau_u^{ToT} \cdot \chi_u \\ \forall s \in S_E : \quad \sum_{u \in \dot{N} \wedge s \in S_E} \chi_u \geq 1 \\ \forall u \in \dot{N} : \quad (\varepsilon_u^{Battery} - \varepsilon_u^{ToT}) \cdot \chi_u \geq \varepsilon_{th} \\ \forall u \in \dot{N} : \quad \chi_u \in \{0, 1\} \end{array} \right. \quad (3.2)$$

Where :

- 1st constraint : The selected UAVs have the required sensors to deal with the event E .
- 2nd constraint : The residual energy in each selected UAV should be higher than a predefined threshold ε_{th} .
- 3rd constraint : χ_u is a boolean decision variable.

3.3 Summary

In summary, although the aforementioned studies in mobile and vehicular cloud shed the light on how to select the most suitable cloud service, they cannot be directly applied for UAVs in which the topology of the network varies fast over time due to the mobility of UAVs in the 3D space which may affect services' QoS such as the latency and the reliability. In addition, The only existing method addressing the services' selection in UAV clouds is a simple method of selection because it's based on Linear integer problem. Simulation results show that the proposed method minimizes as much as possible the response times of UAVs should be applied and minimizes as much as possible the energy consumption should be used. However, this selection mechanism does not aim the client needs (price, quality of service). To the best of our knowledge, none of the existing works highlight the importance of client requirements, that is what motivated us to propose a new service selection method, which addresses the aforementioned issues. The following chapter describes the details of our new solution.

CHAPTER 4

GAME THEORETIC APPROACH FOR SERVICES' SELECTION IN UAV CLOUDS: OUR CONTRIBUTION

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4.1 Introduction

In this chapter, we present our new Game Theoretic approach for Services' Selection in UAV Clouds (GTSS-UC), which enables the client or the requester to select the best service

provider in term of quality of service and price.

The results of our simulations conducted using NS-2 simulator depict the good performance of our solution.

4.2 Background of Game Theory

Game Theory (GT) is a branch of applied mathematics for analyzing the strategic interactions among multiple decision-makers (players). These decision-makers cooperatively or competitively take rational actions that have conflicting consequences [32, 33].

Formally, a game is defined by:

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

4.2.1 Games Examples

1. **The prisoner's dilemma:** Two suspects are arrested, the police think that they're trying to rob a store but the cops only have the evidence to prove that the suspects were trespassing, thus, to establish a connection between the two crimes (trespassing and robbery) the police are going to need one of the criminals to rat out the other. Each of the convicts is going to be privately sequestered in an interrogation room and offered the following deal :

- If no one confesses then 1 month for each.
- If 2 confess then 8 month jail for each.
- If one confess then he will be free and the other will get 12 months in jail.

The prisoner's dilemma

		<i>Player 1</i>	
		<i>Keep Quiet</i>	<i>Confess</i>
<i>Player 2</i>	<i>Keep Quiet</i>	<i>-1, -1</i>	<i>-12, 0</i>
	<i>Confess</i>	<i>0, -12</i>	<i>-8, -8</i>

Figure 4.1: The prisoner's dilemma.

2. **The stag hunt:** We have two hunters going out for a hunt, in the range there are two hares and one stag. The hunters can only bring the equipment necessary to catch one type of animal and they each have to choose this equipment without seeing what the other is going to choose.

- The stag has more meat than the hares combined, but both hunters must chase the stag to catch it.
- Hare hunters can catch all their prey by themselves.

The stag hunt

		<i>Player 1</i>	
		<i>Stag</i>	<i>Hare</i>
<i>Player 2</i>	<i>Stag</i>	<i>3, 3</i>	<i>0, 2</i>
	<i>Hare</i>	<i>2, 0</i>	<i>1, 1</i>

Figure 4.2: The stag hunt.

3. **Traffic lights:** Suppose two cars are driving at each other from perpendicular directions, The stoplight is red for one of them and green for the other.

Traffic lights

		<i>Player 1</i>	
		<i>Go</i>	<i>Stop</i>
<i>Player 2</i>	<i>Go</i>	<i>-5, -5</i>	<i>1, 0</i>
	<i>Stop</i>	<i>0, 1</i>	<i>-1, -1</i>

Figure 4.3: Traffic lights.

4. **The cost allocation:** Three neighboring towns (A, B and C) are in contract with a company to provide water supplies, The project costs 10 million euros for each municipality taken separately for geographic reasons. The manufacturer offers reduced costs of 16, 17, 18 for common contracts between A and B, A and C, and B and C , The contract involving the three cities has a cost of 24.

4.2.2 Types of Games

In [GT](#), games can be classified according to the study in [\[32\]](#) into three main classes:

1. **Cooperative games and non-cooperative games:** A cooperative game allows some players to play together against one or more players, For example (The cost allocation). On the other hand, in a non-cooperative game model the strategic interactions between different players who do not seek to coordinate, For example (The prisoners dilemma).
2. **Simultaneous games and sequential games:** In this case, the players decide their actions either at the same time (The prisoner's dilemma) or conditionally based on what the other players have played (The chess game).
3. **Zero-sum and non-zero-sum games:** Zero sum game is a two player game in which the gain of one of the two players is exactly the cost of the other player.

4.2.3 Nash Equilibrium

A nash equilibrium is a set of strategies, one for each player, such that no player has the incentive to change his or her strategy according to what the other players are doing. In other words it is a law that no one would want to break even in the absence of an effective

police force. For example (Traffic lights), following stoplight is a nash equilibrium, (The stag hunt) both hunting stag or hare is a nash equilibrium.

1. **Pure Strategy Nash Equilibrium :**

It is when players do not randomize between two or more strategy.

2. **A mixed strategy Nash Equilibrium :**

It is a probability distribution over two or more pure strategies.

4.3 Game Theoretic approach for Services' Selection in UAV Clouds

In this section, we will be explaining the functioning of our solution.

4.3.1 Game Description of GTSS-UC

In our approach, we consider two players: the service provider (**UAV**) and the Requester (**R**); Players = {**UAV**, **R**}. Each of the two players has two possible strategies. On one hand, the Requester (**R**) chooses between Consume (**C**) or Do Not Consume (**NC**), it depends on the quality of service and the price offered by the service provider. On the other hand, the service provider can choose between either Offer (**O**) or Not Offer (**NO**) his service to the requester. It is quite clear that the requester seeks to select a service provider offering the best (quality/price) ratio while the service provider determines the price according to its quality of service. Thus, the service provider and requester will select the most appropriate strategy in order to maximize their gains. The balance of the play is the state where no player can increase their winnings if they change strategy. To do this, we relied on Nash's equilibrium to determine this state.

We represent each service by a number of data packets that will be exchanged between service provider and requester. In addition, to determine the gain of each player, we relied on the following quality criteria: successful service offer report Q_{REP} , execution time Q_{ET} , energy consumption Q_{EN} , and service execution price Q_{EP} , where:

1. Reputation Q_{REP} : Depends on the history of providing services to requesters. This criteria is determined by **UAVs** using the following formula.

$$Q_{REP}(s) = \frac{\sum_{i=1}^n R_i}{n}, R_i \in [0, 1]$$

With R_i representing the opinion of requester on the service provider s and n is the total number of requesters.

2. The execution time Q_{ET} : The delay in seconds of service consumption which is the sum of the processing delay and the transmission delay of the data packets of the service s .

$$Q_{ET} = T_{Rrocess}(s) + T_{Trans}(s)$$

3. The energy consumption Q_{EN} : The energy consumption while offering the service which is the sum of energy required for processing and transmission of data.

$$Q_{EN} = E_{Rrocess}(s) + E_{Trans}(s)$$

4. The cost of execution price Q_{EP} : The price of the service offered by the service provider.

4.3.2 Payoff matrix

A payoff matrix is a way to express the result of players' choices in a game, in which strategies of one player are listed in rows and those of the other player in columns and the cells show payoffs to each player (the payoff of the row player is listed first).

Table 4.1 illustrates the gain matrix of Service provider and Requester, where p and $(1-p)$ are the probabilities that the Service provider selects strategies O and NO, respectively, q and $(1-q)$ are the probabilities that the Requester selects strategies C and NC, respectively. We distinguish four combinations of strategies that can be selected by both players:

Table 4.1: Payoff matrix of UAV and R.

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	$1 - q$	

1. **Combination of strategies (Offer and Consume):**

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

In this case, the service provider offers its service and the requester decides to consume it. X_{11} represents the gain of the service provider which is equal to the number of service data packets N multiplied by the price of each packet. However, it is affected by the duration of the service and the energy consumed. In addition, the gain of the requester Y_{11} corresponds to the service consumed in terms of data packets. This gain is also affected by the price and the duration of the service.

2. Combination of strategies (Offer and Do not consume):

- $X_{12} = -N * Q_{EP}$
- $Y_{12} = -M * N$

The service provider offers its service while the requester refuses to consume it. Indeed, the requester refuses to consume a service because of the low quality offered or he has already selected another service provider. X_{12} represents the failure of the service provider to offer its service which is the price of service. In this case, the requester is penalized by multiplying his gain by M which reflects the number of times he has refused to consume a service while the service provider accepts to offer it Y_{12} .

3. Combination of strategies (Do not offer and Consume):

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

In this case, the requester decides to consume the service but the service provider refuses to offer it. The service provider may not offer its service because it is busy (it has offered or wants to offer its service to another requester). If this is not the case, the service provider will be penalized by multiplying the service price by L which represents the number of times it has refused to offer a service while the requester agreed to consume it X_{21} . Y_{21} reflects the failure of the requester to consume the service.

4. Combination of strategies (Do not offer and Do not consume):

- $X_{22} = 0$
- $Y_{22} = 0$

In this case, the gains of service provider and requester (X_{22}, Y_{22}) are zero since both decide to neither offer nor consume the service, respectively.

We note that to normalize the gains of the two players, each quality criteria is standardized and normalized between 0 and 1, by dividing its value by the standard value (max). For example, the service price is normalized based on the max standard price Q_{EP} , i.e., $Q_{EP} = \frac{Q_{EP}}{Max(Q_{EP})}$.

4.3.3 Nash's equilibrium in mixed strategy

The steady state of the game is the state where each player has no interest in changing strategy. To do this, we use Nash's equilibrium in mixed strategy to determine the state where the service provider and requester do not change their Offer and Consume strategies respectively.

Theorem :

There exists a Nash equilibrium in mixed strategy $\{UAV(Offer, p^*), R(Consume, q^*)\}$ in which the service provider chooses the Offer action with a probability $p > p^*$ and the requester chooses the action Consume with a probability $q > q^*$.

Evidence:

The mixed strategy of service provider is defined as follows: $P = (p, 1 - p)$ and the gains of requester are:

- $u_R(Consume) = Y_{11} * p + Y_{21} * (1 - p) = p * (Y_{11} - Y_{21}) + Y_{21}$
- $u_R(DoNotConsume) = Y_{12} * p + Y_{22} * (1 - p) = p * Y_{12}$

The requester select the Consume action when $u_R(Consume) > u_R(DoNotConsume)$. Therefore, we get:

- $p > p^*$ where $p^* = \frac{-Y_{21}}{Y_{11} - Y_{21} - Y_{12}}$ with $0 < p^* \leq 1$.

The mixed strategy of the requester is defined as follows: $Q = (q, 1 - q)$ and the gains of the service provider are:

- $u_{UAV}(Offer) = X_{11} * q + X_{21} * (1 - q) = q * (X_{11} - X_{12}) + X_{12}$
- $u_{UAV}(DoNotOffer) = X_{21} * q + X_{22} * (1 - q) = q * X_{21}$

The service provider selects the Offer action when $u_{UAV}(Offer) > u_{UAV}(DoNotOffer)$. Therefore, we get:

- $q > q^*$ where $q^* = \frac{-X_{12}}{X_{11} - X_{12} - X_{21}}$ with $0 < q^* \leq 1$.

We conclude that when the probability that the service provider will choose the action to consume is greater than or equal to q^* and the probability that the requester will choose the action to offer is greater than or equal to p^* , the two players do not change their strategies, which corresponds to the state of balance of the game.

4.3.4 Examples Scenario of GTSS-UC

In this section, we take a look at a simple example that we hope better illustrate and give a clearer view of the functionality of GTSS-UC approach. The example is shown in the Figure 4.4.

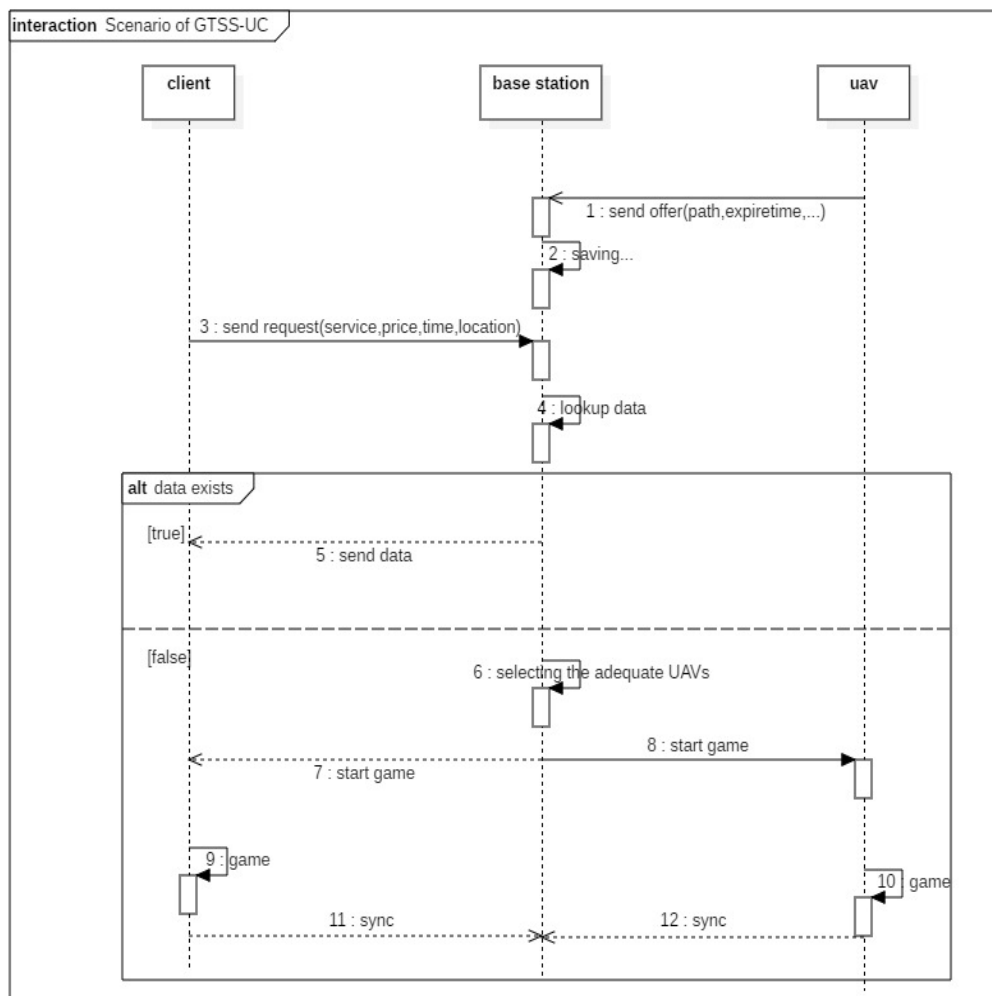


Figure 4.4: Example Scenario of GTSS-UC.

In this scenario, we have a base station that the service provider can send information from time to time. This information consists of several parts, like:

- The UAV's id.
- The residual energy of the UAV, where the UAV is headed (Path and destination).
- The available services or offers that the UAV can provide (Photography, Sensors, Video recording,...etc.).
- The price of the service.
- The time frame that the UAV can provide the service. For example: from 8:00 AM to 11:00 AM.

With time, we notice that the database of the base station fills up with offers from different service providers. If the client requires a specific service then he sends a request to the ground station. This request contains many requirements that have to be met for the client to choose a specific service provider, for instance:

- The type of service required by the client like: Photography, Video recording,...etc.
- The max price of the service (The price of the service should not exceed the max price listed by the client).
- The location of the event or where the client requires the service.
- The time frame that specifies when the client needs the service.

If the client requires information, then the base station searches the database. If the ground station finds the required information then it sends it to the client. To give an example: An accident happened somewhere, a client requests a UAV to record the aftermath, then the video of the incident is stored in the database of the base station. Another client requests the same file from the ground station. In this case the ground station finds the file and sends it back to the client.

In case the base station can't find an adequate response to the client's request from the database, then it sends the client a list of UAV's that verify the requirements of the request. At the same time the base station sends the client's request to all the UAV's in the list notifying them of the possibility that the client may select any one of them.

4.3.5 Simulation results

To evaluate our proposed method performance, we used NS-2 [34] to simulate the aforementioned scenario. The parameters of the simulation are listed in the table 4.2 below.

Table 4.2: Simulation configurations

Parameter	Values
Simulated area	7x7 (Km)
Transmission range	250 m
Velocity	[10-30] m/s
Number of UAVs	50, 100, 150, 200
Number of Requests	5, 10
Number of Services	5
Simulation time	200 s

We chose the following performance metrics to illustrate the results of our simulation:

- **Successful Execution Ratio (SER):** Represents the number of successful service consumptions in the time frame agreed upon relative to the number of services offered.
- **Service Gain :** Represents the collective gain of the clients after consuming services. We determine this gain using Y_{11} .
- **Average Response Time (ART):** Represents the total time from the the sending of the request to the base station to the reception of the first data packet.

Figure 4.5 represents the successful execution ratio relative to the number of UAVs in the area. We can see that every time we increase the number of UAVs in the network, the SER also increases, and that is due to the increasing availability of the drones which means more services and offers can be made to the clients, thereby increasing the chances that a client can find a suitable offer.

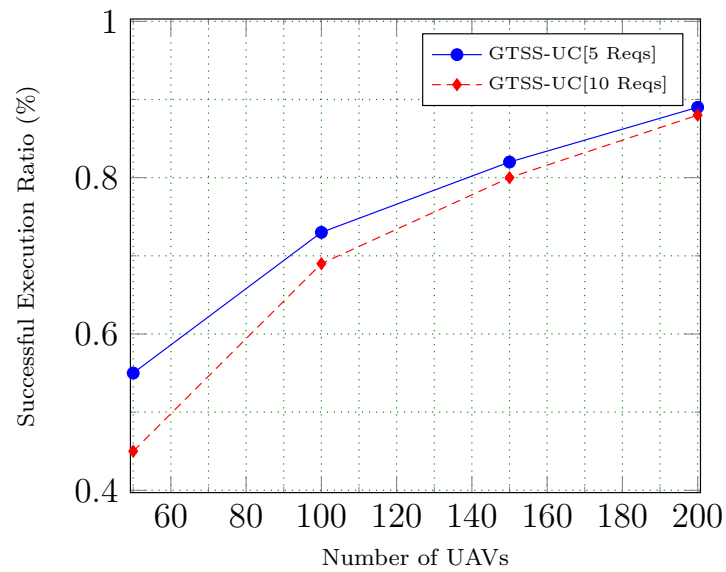


Figure 4.5: Successful Execution Ratio VS UAVs density.

The curves of Figure 4.6 illustrates the service gain relative to the number of UAVs in the area. We notice that the service gain decreases with the increase of UAVs in the area because of the increasing number of drones verifying the conditions of a specific request.

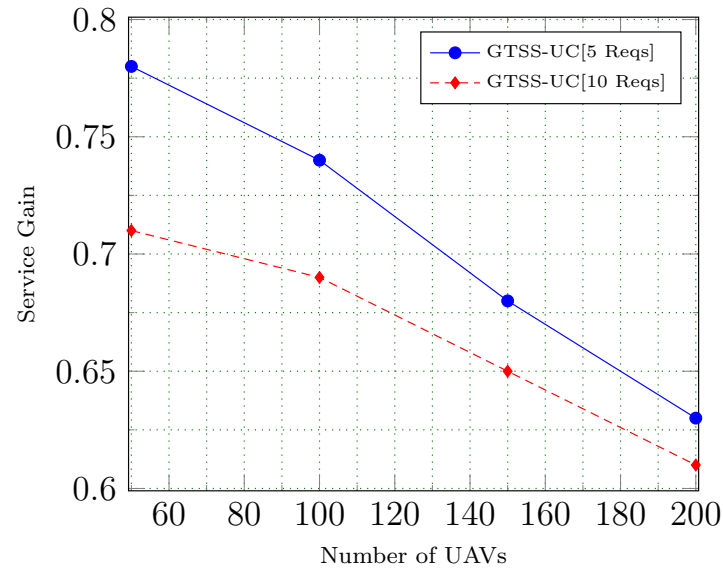


Figure 4.6: Service Gain VS UAVs density.

Figure 4.7 represents the average response time relative to the number of UAVs in the area. We tried to put the UAVs as far apart as possible and as we can see that with 50 UAVs the response time was the highest because the average distance between the client and the UAV is high due to the sparsity of the UAVs in the area. We can also see that by increasing the number of UAVs we minimize the average response time.

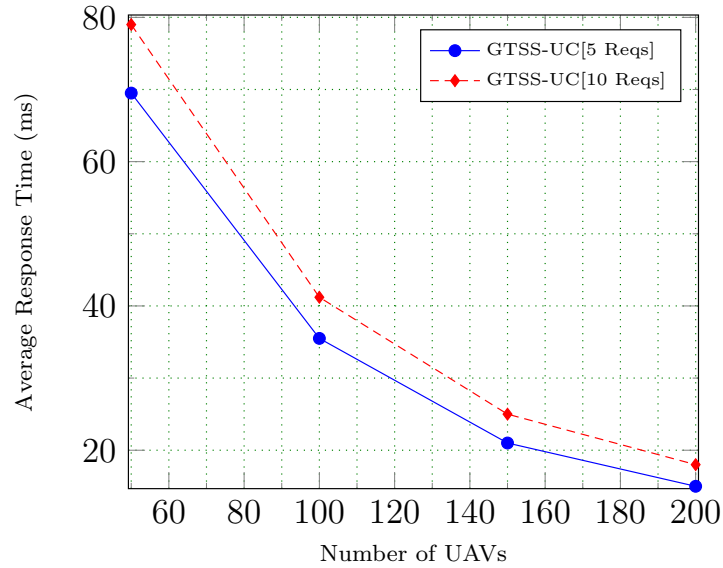


Figure 4.7: Average response time VS UAVs density.

4.4 Conclusion

In this chapter, we presented our new Game Theoretic approach for Services' Selection in UAV Clouds and discussed its performance and effectiveness through NS-2 simulator.

CHAPTER 5

CONCLUSION AND FUTURE PERSPECTIVES

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5.1 Summary of our Work

Revolutionary improvements in the technology of [UAVs](#) in the past few decades have led to highly advanced [UAVs](#) that come in different shapes, sizes, capabilities, and functions. Nowadays, [UAV](#) clouds have attracted wide attentions from both industrial and academic communities as a new paradigm due to their flexible and elastic services, which is expected to play a vital role in the future of wireless networks. In this work, we have presented a new Game Theoretic approach for Services' Selection in [UAV](#) Clouds.

As a first step, we have introduced Cloud Computing and presented an overview of [UAV](#) Clouds. We have also presented the services' selection and their challenges in [UAV](#) Clouds.

As a second step, a brief state-of-the-art of the existing services' selection of mobile, vehicular, and [UAV](#) Clouds is undertaken.

As a third step, we have presented our solution [GTSS-UC](#).

5.2 Future Perspectives

To build on the work accomplishments, some future perspectives should be considered to design new Offering/Selection approaches. One of the future work directions is to implement a new service's selection techniques minimizing the time and cost. Another direction for extending [GTSS-UC](#) is to make it more decentralized by decreasing the role of the base station.

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