PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITE KASDI MERBAH OUARGLA

Faculty of New Information and Communication Technologies

Department of Computer Science and Information Technology

Memory of

PROFESSIONAL MASTER

Domain: Mathematics and Computer Science

Specialty: Network administration and Security

Presented by

ABBASSI Rekia and HAMADOU Kamar

Theme

Fuzzy logic based on UAV-cloud for service selection

The jury composed of:

Dr.CHERADID Abdelatif	UKM Ouargla	President
Dr.KHALDI Yacine	UKM Ouargla	Examiner
Dr.BEN BEZZIANE Mohamed	UKM Ouargla	Supervisor

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Dedication

I dedicate the fruits of my efforts to my dear parents, who taught me to trust in Allah, believe in hard work, and showed me that great things can be achieved with little. They stayed up all night to bring us joy and happiness, especially my tender father. May Allah continue to bless and support me throughout my life.

To the source of tenderness, warmth, and safety, to the one whom my soul and heart adore , and whom I would sacrifice my life for, my dear mother .

And to Mr.CHEKARI Ahmed who helped me with his advice and experience.

To the angels God has blessed me with so that I may know the taste of the beautiful life through them, my sisters.

To the one who supported me with everything, and was

the best helper for my brother.

To my best friend HAMADOU Kamar, with whom

I shared both the good and the challenging moments during

our years of studying together.

To all my beloved ones.

ABBASSI Rekia

Dedication

I thank God Allah first and last for the great blessings He has bestowed upon me.

Then I thank the one who honored me, my first friend in life, the one who embraced me, the one who kissed me, and the one who anointed me with tears, to my pure angel and my strength after God Almighty, my dear mother.

To the one who encouraged me throughout his life until his death, to the greatest man in my life, to the greatest blessing who passed away, my father, may God have mercy on him.

To those who tirelessly extended their hands, my brothers

may God bless you as my support in this life.

To my eyes that cry for my sadness and my heart

that laughs for my joy to my friend and companion ABBASSI Rekia, may God keep your smile.

To my other family, my dear friends.

To everyone who contributed a message to my school life, and to all of them I dedicate this

HAMADOU Kamar

Abstract

The emergence and development of FANET (Flying Ad hoc Network) have contributed to the advancement of technologies in many fields, allowing communication without the need for infrastructure. FANET is an ad hoc network that uses unmanned aerial vehicles (UAVs) to communicate and provide various services.

In this case, drones can access a wide range of services like internet access, information, storage, and computing as a service thanks to UAV cloud. But given the high random Because of their mobility, client drones must first identify service providers who can meet their needs before they can use the necessary services.

In this project, we propose a new approach called FL_DS, which uses fuzzy logic to solve decision making problems and improve the selection of the best services for UAV clients. This proposed approach is compared with another approach, Simple Additive Weighting (SAW). We utilized the OMNeT++ simulator with the INET framework to create a robust simulation environment. The results demonstrated the effectiveness of fuzzy logic in enhancing network resource management and service quality in FANET.

Keywords : FANET ,UAV Cloud, FL_DS, Decision Making ,SAW ,OMNeT++,INET

Résumé

L'émergence et le développement de FANET (Flying Ad hoc Network) ont contribué à l'avancement des technologies dans de nombreux domaines, permettant la communication sans avoir besoin d'infrastructure. FANET est un réseau ad hoc qui utilise des véhicules aériens sans pilote (UAV) pour communiquer et fournir divers services.

Dans ce cas, les drones peuvent accéder à une large gamme de services comme l'accès à Internet, l'information, le stockage et l'informatique en tant que service grâce au cloud UAV. Mais compte tenu du caractère aléatoire élevé de leur mobilité, les drones clients doivent d'abord identifier les fournisseurs de services qui peuvent répondre à leurs besoins avant de pouvoir utiliser les services nécessaires.

Dans ce projet, nous proposons une nouvelle approche appelée FL_DS, qui utilise la logique floue pour résoudre les problèmes de prise de décision et améliorer la sélection des meilleurs services pour les clients UAV.

Cette approche proposée est comparée à une autre approche, la pondération additive simple (SAW). Nous avons utilisé le simulateur OMNeT++ avec le framework INET pour créer un environnement de simulation robuste. Les résultats ont démontré l'efficacité de la logique floue pour améliorer la gestion des ressources réseau et la qualité de service dans FANET.

Mots clés : FANET ,UAV Cloud, FL_DS, La prise de décision, SAW ,OMNeT++,INET.

ملخص

ساهم ظهور وتطوير شبكة الـ FANET في تقدم التكنولوجيا في العديد من المجالات، تسمح بالاتصال دون الحاجة إلى البنية التحتية .

شبكة الـ FANET هي شبكة مخصصة تستخدم المركبات الجوية غير المأهولة (UAVs) للتواصل وتقديم خدمات مختلفة.

في هذه الحالة، يمكن للطائرات بدون طيار الوصول إلى مجموعة واسعة من الخدمات مثل الوصول إلى الإنترنت والمعلومات والتخزين والحوسبة كخدمة بفضل سحابة الطائرات بدون طيار. ولكن نظرًا لارتفاع معدل النقل العشوائي، يجب على الطائرات بدون طيار العميل أولاً تحديد مقدمي الخدمات الذين يمكنهم تلبية احتياجاتهم قبل أن يتمكنوا من استخدام الخدمات اللازمة.

في هذا المشروع، نقترح نهجًا جديدًا يسمى FL-DS، والذي يستخدم المنطق الضبابي لحل مشاكل اتخاذ القرار وتحسين اختيار أفضل الخدمات لعملاء الطائرات بدون طيار. تتم مقارنة هذا النهج المقترح بنهج آخر، وهو الترجيح الإضافي البسيط (SAW) . لقد استخدمنا محاكي OMNeT++ مع إطار عمل INET لإنشاء بيئة محاكاة قوية. أظهرت النتائج فعالية المنطق الضبابي في تحسين إدارة موارد الشبكة وجودة الخدمة فيFANET .

الكلمات المفتاحية: FANET، سحابة UAV، FL_DS، SAW،اتخاذ القرار، OMNeT++، INET.

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Abreviations list

GPS	Global Positioning System
UAV	Unmanned Ariel Vehicle
FANET	Flying Ad-Hoc Network
SAW	Simple Additive Weighting
MANET	Mobile Ad-Hoc Network
VANET	Vehicular Ad-Hoc network
LOS	Line-of-Sight
GS	Ground Station
RWP	Random way point mobility model
SRCM	Semi random circular movement model
MPB	Mission Plan Based Mobility Model
PPRZM	Paparazzi mobility model
GM	Gauss-Markov mobility model
MM	Mass Mobility Model
VCC	Vehicular Cloud Computing
QoS	Quality of Service
FL-DS	Fuzzy Logic Discision System
FL	Fuzzy Logic
MEC	Mobile Edge Computing
UDP	User Datagram Protocol
PD	Provider drones
CD	client drones
Qee	Execution energy
Qet	Execution Time

Qep	Execution Price
OMNet++	Objective Modular Network Test-bed in C++
IDE	Integrated Development Environment
TCP	Transmission Control Protocol
ICMP	Internet Control Message Protocol
IP	Internet Protocol
PPP	Point-to-Point Protocol

General Introduction

General Introduction

Recent advancements in wireless technology have been observed in our daily lives especially due to the wide availability of low-cost Wi-Fi radio interfaces and other devices like GPS, sensors, micro embedded computers, etc. All these innovative devices have paved the way for the development of small intelligent flying vehicles, for example, Unmanned Aerial Vehicles (UAVs), leading to the creation of a new type of network called Flying Ad hoc Network (FANET).

A predominant challenge within FANETs is the efficient selection of services, a task complicated by the network's highly dynamic nature. Without effective service selection mechanisms, the network may suffer from poor performance, leading to unreliable communication and diminished user satisfaction. In such environments, traditional service selection methods often fail to adjust to the rapid changes in network topology and the fluctuating quality of service, resulting in suboptimal operational outcomes.

Our study proposes fuzzy logic as a robust solution for service selection in FANETs, offering more accurate and flexible decision-making compared to traditional methods. Compared to the Simple Additive Weighting (SAW) method, fuzzy logic improves adaptability, accuracy, network reliability, and user satisfaction, highlighting the potential of advanced computational techniques in dynamic network environments.

This memory consists of three chapters:

Chapter I: Here we provide overview of FANET networks

Chapter II: We will present two mathematical methods of service selection and their formulation.

Chapter III: We will make a comparison between the proposed method based on fuzzy logic and the simple weighted method.

Chaptre I: Overview of FANET

I.1. Introduction

The FANET network has recently contributed to the development of technologies in many fields, it is a wireless network designed to connect drones. It allows communication without the need for infrastructure, and is also used in many applications such as search and rescue, environmental monitoring.

In this chapter we will provide an overview of FANETs, explaining their basic concepts such as characteristics, architectures, applications, and mobility models.

I.2. Definition of FANET network

FANET is a form of Unmanned Ariel Vehicle (UAV) also known as drones flying in the sky and they communicate with each other, transfer the data and signals between each other without any human experts and without any physical connectivity between the nodes[1]. Small group of UAVs form networks called flying ad hoc networks(FANET). FANETs are the extension of a mobile ad hoc network (MANET) or a vehicular ad hoc network (VANET) with integrated sensors, cameras, transmitters, receivers[2]. In the FANETs network there are two modes of communication In UAVs communication, each UAV communicates with the other UAV directly or using multi-hop communication. In the other kind of communication, the UAV create the connection with an infrastructure like a ground base or satellite to transfer the data [3].

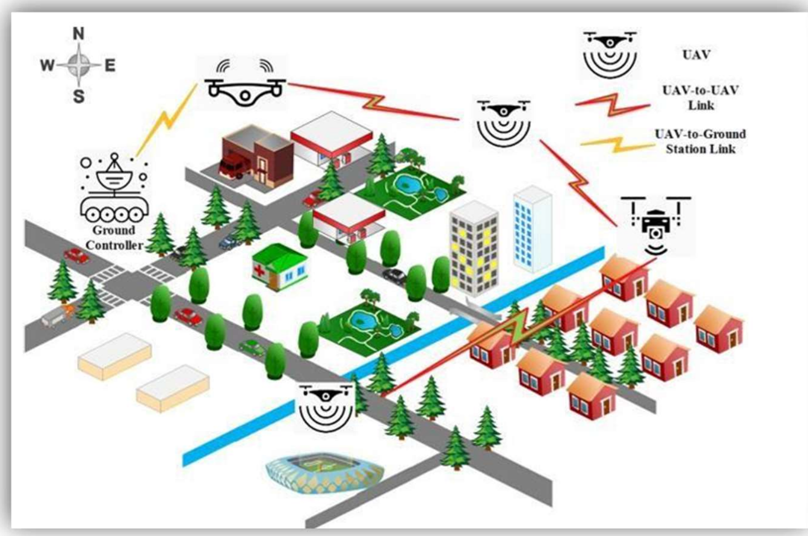


Figure I.1.FANET network.

I.3. Characteristics of FANET

FANETs have some unique characteristics that make them different from other ad-hoc networks. Some of the major characteristics are given as follows:

I.3.1.Node Mobility

In node mobility, the degree is higher than MANET and VANET(Vehicular Ad-Hoc Network). The UAV has a speed of 30-460 km/h, and this speed causes the communication problem between UAVs [2].

I.3.2.Mobility Model

In the majority of mobility models, the map is recalculated after every modification to the flight plan. Every model has pros and cons, and they all need to be dynamic [4].

I.3.3.Network Topology

In FANET, the degree of node(UAVs) mobility is higher, which leads to frequent and random change in the network topology [5].

I.3.4.Node Density

Node density can be defined as the average of nodes in a unit area. In FANET, the nodes flying in the sky are separated by a large distance, so the density is low in FANET [6].

I.3.5.Radio Propagation

When it comes to radio propagation model, FANETs have a great advantage of line-of-sight (LoS) over other ad-hoc networks. In FANET, UAVs can have a clear LoS among them due to their free mobility in the air. By contrast, in other ad-hoc networks, no LoS between the source and the destination owing to the geographical structure of the terrain[5].

I.3.6.Energy Constraint

Energy limitation is one of the major design issues in ad-hoc networks. In FANET, it depends on the size of the UAV. Most of the large UAV are not power-sensitive, where as energy limitation is a concern for mini-UAVs [4].

I.3.7.Localization

The process of localizing entails locating every UAV. Due to the rapid changes in the environment, it is necessary to have highly localized information at short time intervals. GPS will disseminate information about new positions to the network once every second, but this is insufficient. In order to broadcast his location to all other UAVs in the network at any given time, each UAV needs to have a GP and an initial measurement unit [6].

I.4. Communication architectures

A communications architecture defines how information is exchanged between the ground station and a UAV, or between the UAVs themselves. Two different architectures centralized and decentralized can be used to link several UAVs:

I.4.1.Centralized Communications

All UAVs linked directly with the ground station(GS) as illustrated in **(Figure I.2)**. In this topology, the UAVs also communicate with each other via the GS[7].

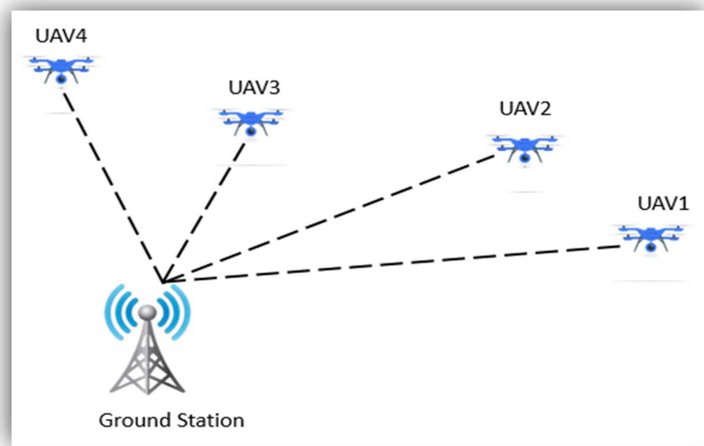


Figure I.2. Centralized communications.

I.4.2.Decentralized Communications

In a decentralized architecture, the UAVs can communicate directly or indirectly without relying on GS. We introduce three communication architectures for the decentralized architecture:

I.4.2.1.UAV Ad Hoc Network

As seen in **(Figure I.3)**, in a UAV ad-hoc network, every UAV participates in the data forwarding process for every other UAV in the network. In this particular architecture, the backbone UAV acts as a gateway between the GS and the member UAV. Two radios are often installed on the backbone UAV: a high power long-range radio and a low power short-range radio. The GS requires high power long-range radio transmission, while low power short-range radio is utilized for communication between the UAVs. The network's coverage area is significantly increased since in the UAV ad-hoc networking design, only one backbone UAV is linked to the GS [8].

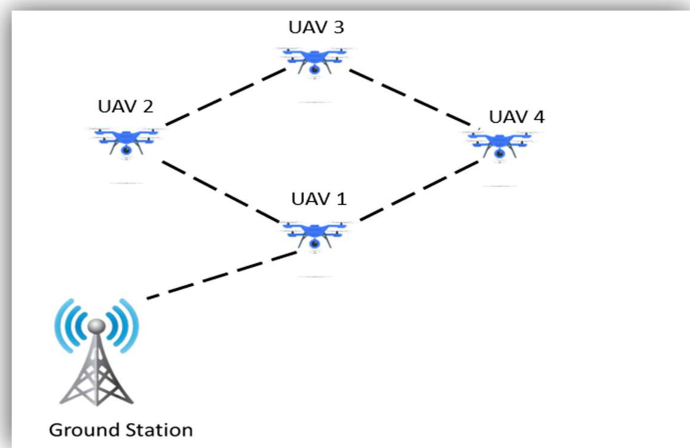


Figure I.3.UAV Ad Hoc Network.

I.4.2.2.Multi-Group UAV Network

In **(Figure I.4)**, a multi-group UAV network is displayed. In this network, individual UAVs establish ad hoc UAV networks, each having a backbone UAV that connects to the ground station. Intra-group communications (e.g. communications within a same group) are conducted within a UAV ad hoc network described in Figure 02, while inter-group communications (e.g., communications involving two different groups) are performed via respective backbone UAVs and the ground station. It is important to remember that the multi-group UAV network architecture can be thought of as a network that combines UAV ad hoc networks with centralized UAV networks [8].

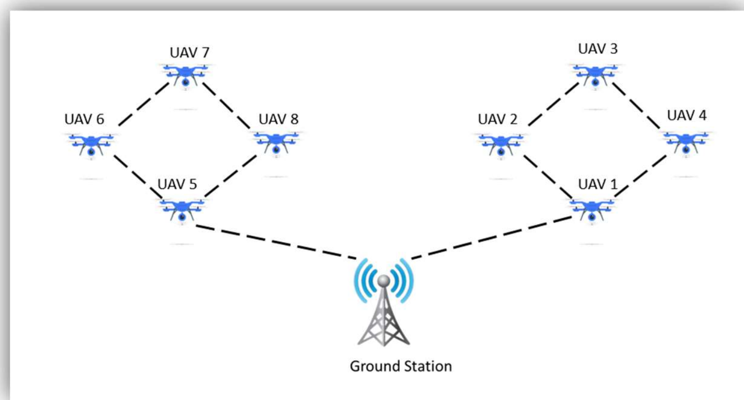


Figure I.4. Multi-Group UAV Network.

I.4.2.3.Multi-Layer UAV Ad Hoc Network

Another architecture in the form of networking multiple groups of heterogeneous UAVs is the multi-layer UAV ad-hoc network. As illustrated in **(Figure I.5)**.As with the lowest layer of the multi-layer UAV ad hoc network architecture, the UAVs within a single group create a UAV ad hoc network. The backbone UAVs of all groups make up the upper-layer UAV ad hoc network. In contrast to the multi-group UAV network, the multi-layer UAV ad hoc network has a single backbone UAV that is connected to the GS directly. In this network, Information sharing between any two UAV groups in this network does not require going via the GS. Because the GS only processes the data that are intended for it, it has a much lighter computational and communication load [9].

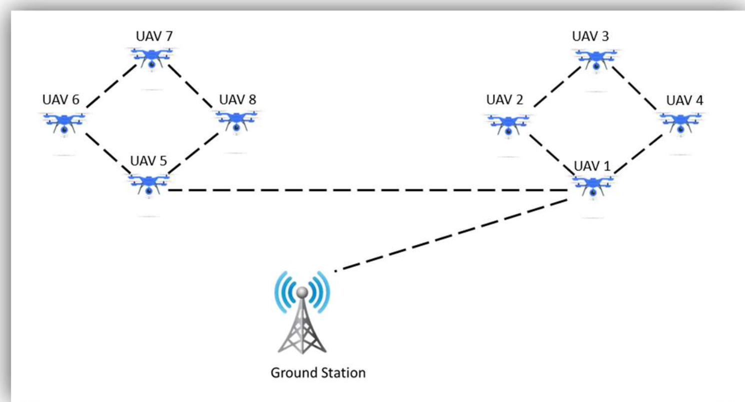


Figure I.5. Multi-Layer UAV Ad Hoc Network.

I.5. FANET Applications

Three main applications of FANETs can be distinguished as follows [10]:

- ❖ **Multi-UAV cooperation**
  - Target detection technologies like thermal and vision cameras can be utilized in UAVs to identify objects and individuals.
  - Tracking and monitoring in disaster situations: UAVs aid in flood direction assessment, predicting damage exposure, and aiding in earthquake rescue operations by identifying collapsed population-dense buildings like hospitals and schools.
  - Emergency situations**:** UAVs are utilized in the construction industry for safety checks, monitoring progress, and providing temporary wireless coverage during emergencies and outages of ground base stations.

❖ **UAV-to-Ground tasks**

- Public and civilian applications: UAVs, particularly small quadcopters, are extensively utilized in public and civilian applications due to their cost-effectiveness and flexibility compared to ground-based infrastructure.
- Search and rescue missions: UAVs are crucial in search and rescue missions, managing disasters, and ensuring public safety. FANETs provide communication coverage, timely disaster warnings, and faster rescue operations. UAVs can also carry medical equipment to inaccessible areas, making SAR operations faster in situations like avalanches and wildfires.

❖ **UAV-to-VANET collaborations between UAVs and vehicles**

- Roadway traffic monitoring: FANETs can replace labor and complex observational infrastructure for road traffic monitoring, detecting crashes and reporting incidents faster than incident commanders. UAVs capture real-time videos for road safety.
- Data packet delivery: Data delivery to mobile ad hoc nodes is challenging due to the lack of reliable forwarding paths. UAVs are used as airborne communication relays to deliver data collected by ground devices to distant control centers.
- Route guidance: VANETs struggle with inadequate routing due to high vehicle mobility. UAV-assisted VANETs use multi-hop relays to transmit data between vehicles and UAVs, providing route guidance and routing improvement.

I.6. Mobility models

Models of mobility Show how a node moves and how its acceleration, velocity and location vary over time. To build a realistic simulation environment, mobility models are employed. It demonstrated how employing alternative mobility models can drastically alter an ad hoc protocol's performance [11].

In this network form FANET we can define these models:

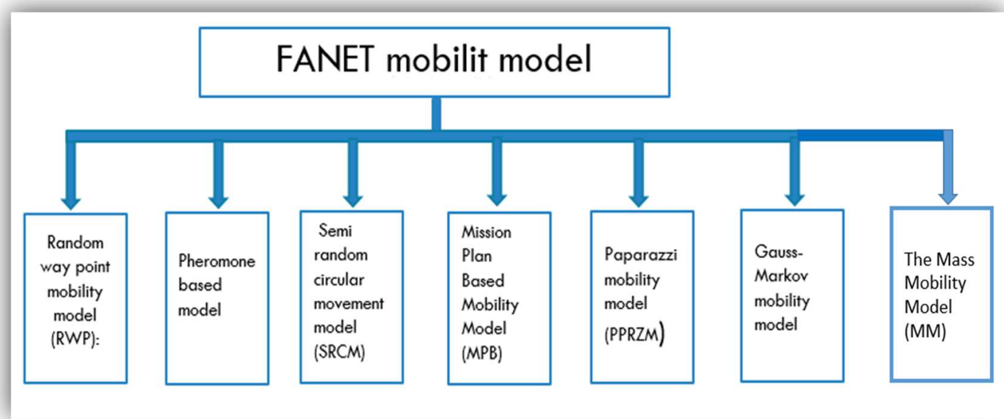


Figure I.6. Different models of mobility.

I.6.1.Random way point mobility model (RWP)

The Random Way Point Model, or RWP, is a straight line. Every UAV node chooses a random destination, travels there at a random speed, and stops for a random amount of time. The node selects a new, random point and moves at that location with a different speed value when the stop time expires. UAVs use predetermined probabilities to determine what to do [11].

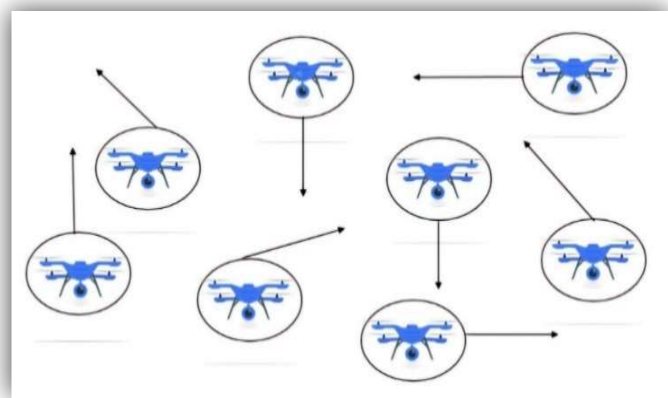


Figure I.7. Random way point mobility model (RWP).

I.6.2.Pheromone based model

The pheromone model uses a pheromone map to guide UAV movements. Each UAV identifies the area it has scanned and broadcasts this map to other UAVs. To get the most coverage, UAVs move through low-pheromone concentration areas. Furthermore, even though the random model is straightforward, it typically produces mediocre outcomes [12].

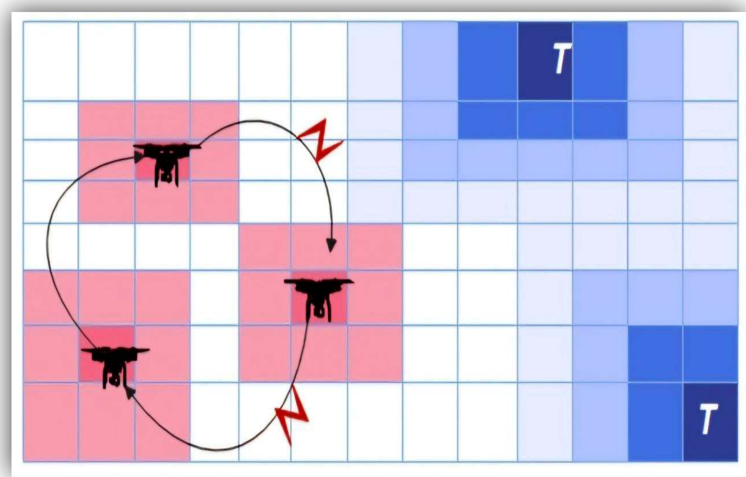


Figure I.8. Pheromone based model.

I.6.3.Semi random circular movement model(SRCM)

This mobility model is intended for UAVs that move in curved paths [13].This model is designed to move in a circle around a stationary area. It can be applied to situations involving search and rescue operations in which the circling zone should be a missing victim [14].

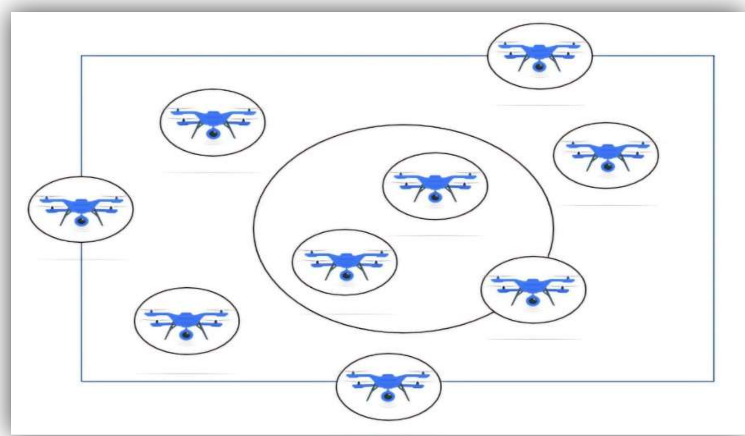


Figure I.9. Semi random circular movement model(SRCM).

I.6.4.Mission Plan Based Mobility Model (MPB)

Aircraft moving toward or away from a destination using a mobility model based on a mission plan. Each aircraft has a starting point and an ending point that are chosen at random, together with information on flight time and velocity. An airplane will reverse course and continue its round-trip journey if it reaches its destination before the allotted flight time[11]. When the MLB Mobility Model period expires, mobility files are updated and generated [15].

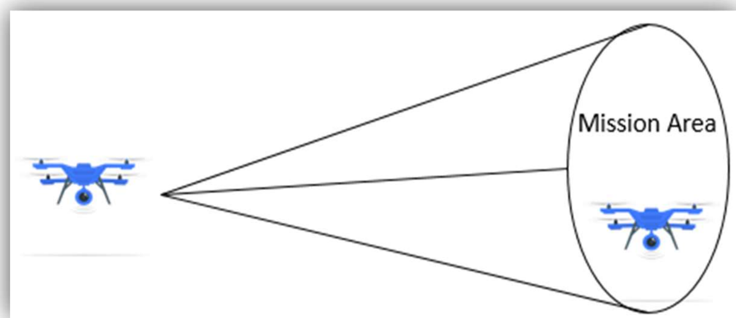


Figure I.10. Mission Plan Based Mobility Model(MPB).

I.6.5.Paparazzi mobility model (PPRZM)

Based on the state machine, the paparazzi mobility model is a stochastic mobility model that mimics the actions of paparazzi UAVs. Compared to RWP, PPRZM behaves more like the actual traces .Given that PPRZM provides a realistic movement scenario, it may be used to assess any communication protocol within the setting of a swarm of cooperative UAVs. Experts categorized the movements of Paparazzi UAVs into five possible types [13].

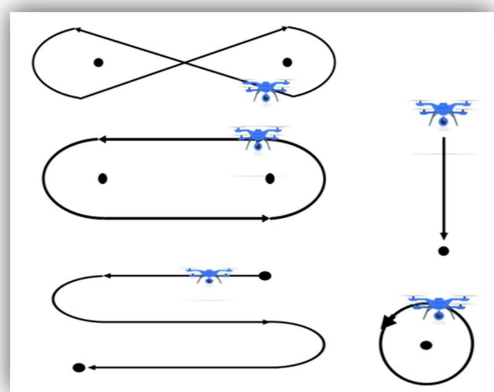


Figure I.11. Paparazzi mobility model (PPRZM).

I.6.6.Gauss-Markov mobility model (GM)

The Gauss-Markov Mobility Model simulates the behavior of UAVs in swarms. It permits different simulated area sizes. Because nodes move so quickly, they constantly modify their places based on past locations. The model's memory determines the drone trajectories. Every node has an initial direction and speed. Movement updates happen at predetermined intervals, recalculating direction and speed using a random variable and the previous instance [11].

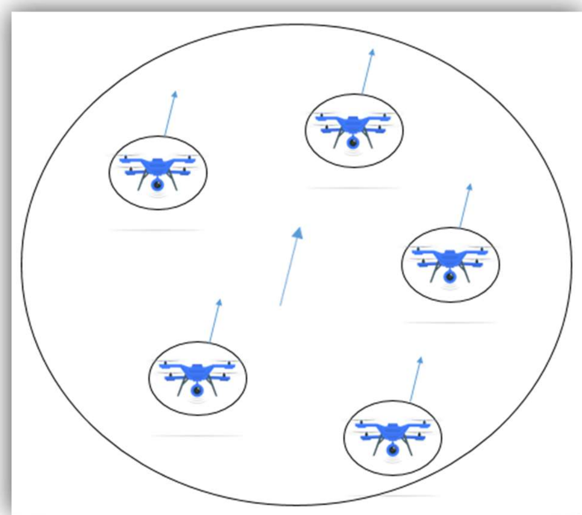


Figure I.12. Gauss-Markov mobility model (GM).

I.6.7.The Mass Mobility Model (MM)

In this concept, the drone first travels in a straight line before turning. This moving time, which has a mean of five seconds and a standard deviation of 0.1 seconds, is a random integer that is normally distributed. When it turns, the direction it will go in is a randomly generated number that is regularly distributed, with a standard deviation of thirty degrees and an average equal to the direction it was moving in before. Together with a regulated mean that ranges from 0.1 to 0.45 (unit/sec) and a standard deviation of 0.01 (unit/sec), its velocity is likewise a normally distributed random integer [16].

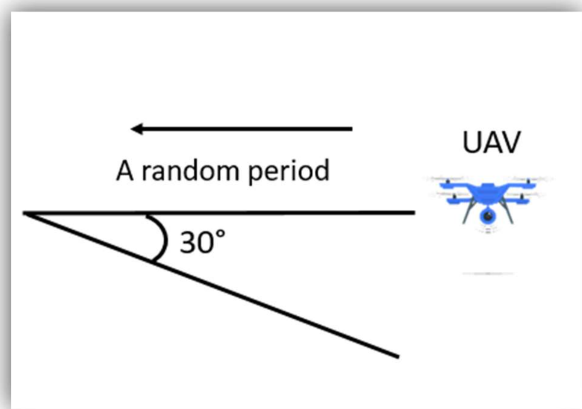


Figure I.13. The Mass Mobility Model (MM).

I.7.Conclusion

In this chapter, we provided an overview of flying ad hoc networks (FANETs) focusing on their definition and characteristics and outlining their application areas. In addition to mobility models.

Chaptre II: Service Selection

II.1. Introduction

The previous chapter discussed FANETs, an ad hoc network with unmanned aerial vehicles (UAVs) communicating to achieve common goals. Vehicular Cloud Computing (VCC) emerged as a solution for UAVs to securely and real-timely provide services, enhancing resource management and application execution. Vehicular Cloud Computing (VCC) represents an expansive new paradigm in cloud computing, capitalizing on underutilized vehicle resources such as network connectivity, computing power, storage and sensing capacity, which can be shared. These resources encompass capabilities such as data processing, communication, storage, and sensing. In this context, some vehicles act as resource providers, while others operate as client [17].

Despite the use of vehicular cloud computing, the problem still exists because the client chooses the first drone provider he finds without considering Quality of Service (QoS) factors. This means that the customer chooses the provider only based on availability, ignoring other factors like reliability, performance, or other service quality parameters. Even while this approach may be straightforward and useful, it has several limitations. If quality of service is neglected, the client may end up with a provider who cannot meet their particular needs. The selected provider may have worse performance, restricted capabilities, or other inconveniences that could negatively impact the overall experience of the service.

In this chapter, we introduce a new approach, named FL-DS, which aims to improve the discovery and selection of the best services for UAV clients in a UAV (cloud computing for vehicles) cloud environment. To achieve this goal, we use fuzzy logic to model and solve decision-making problems. This approach uniquely adapts to the dynamic and mobile nature of FANETs, which helps in optimal service availability and quality. We will compare it to a traditional approach «Simple Additive Weighting (SAW)».

II.2. Fuzzy logic

The idea of fuzzy logic (FL) was first introduced in 1965 by Lotfi Zadeh . The concept of fuzzy logic comes from the observation that Boolean variable, which can only take two values (true or false) is poorly suited to the representation of the most common phenomena. While logic classical considers that a proposition is either true or false, fuzzy logic distinguishes an infinity of values of truth (between 0 and 1). This is therefore a generalization of the binary logic to multivalued logic.

Fuzzy logic makes it possible to process linguistic variables whose values are words or expressions from natural language [18].

II.3. Concept of fuzzy subset

Fuzzy set theory is a mathematical theory whose main objective is the modeling of vague and uncertain notions of natural language. This theory makes it possible to express the idea of a partial membership of an element to a set.

In classical set theory, a subset A of B is defined by a membership function$\mu_A(x)$ which characterizes any element x belonging to B. This function takes the value 1 if x belongs to A and the value 0 otherwise [19]:

$$\mu_A(x) = \begin{cases} 1 & x \in A \\ 0 & x \notin A \end{cases}$$

In fuzzy logic, a fuzzy subset A of B is defined by a membership function $\mu_A(x)$that can take different values between 0 and 1, depending on the degree of belonging of the element x to the subset A [19].

$$\mu_A(x) = [0 \rightarrow 1]$$

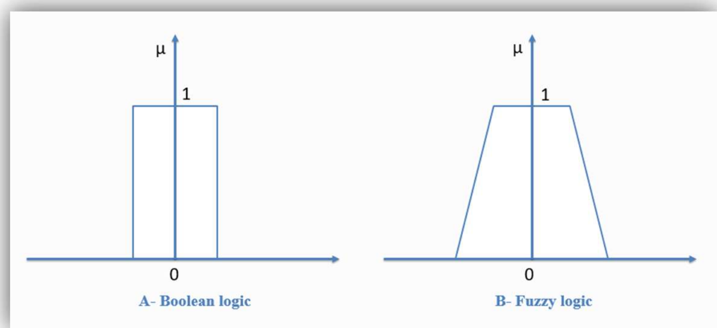


Figure II.14. Membership function characterizing a classical set and a fuzzy set

II.4. The universe of discourse

The universe of discourse represents the reference set or the domain of variation of the linguistic variable, or domain of operation of the process in the case of adjustment [20].

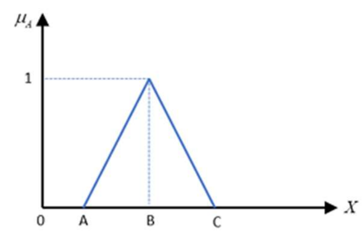
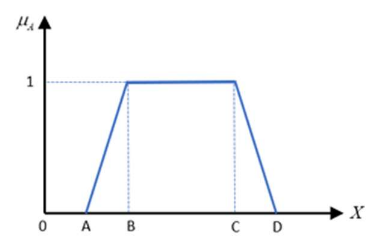
II.5. Linguistic variables

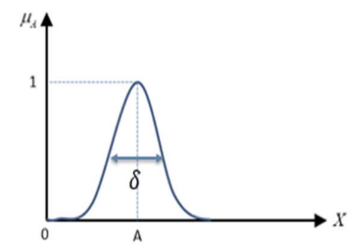
Linguistic variables are an essential element of fuzzy logic. Unlike traditional variables, which are defined by numbers, linguistic variables are based on words and phrases. When describing a situation, phenomenon or process, vague expressions such as "some, many, often, hot, cold, fast, slow, large, small..." are often used. These expressions form what are called linguistic variables in fuzzy logic [21].

II.6. Representation of membership functions

We represent the linguistic variables by their membership functions. Therefore, each fuzzy subset A_i is associated with a membership function $\mu_{Ai}(x)$ where x is the linguistic variable. Such that, each point x is associated with a precise value of $\mu_{Ai}(x)$ which designates the degree of belonging of x to A. Several forms can represent the most used membership functions are represented in the following table [22]:

Table II.1: Membership functions forms.

Function	Algebraic form	Graphic form
Triangular function	$\mu_A(x) = \begin{cases} 0 & x < A \text{ or } x > C \\ \frac{x-A}{B-A} & A \le x < B \\ 1 & x = B \\ \frac{C-x}{C-B} & B \le x \le C \end{cases}$	
Trapezoidal function	$\mu_A(x) = \begin{cases} 0 & x < A \text{ or } x > D \\ \frac{x-A}{B-A} & A \le x < B \\ 1 & B \le x < C \\ \frac{D-x}{D-C} & C \le x \le D \end{cases}$	

Gaussian function	$\mu_A(x) = Exp\left[-\left(\frac{x-A}{\delta}\right)^2\right]$	

II.7. Fuzzy logic operators

Linguistic variables are linked to each other at the level of inference rules by AND or OR operators. These are fuzzy logic operators, which operate on the membership functions representing linguistic variables.

Thus, for two fuzzy sets A and B corresponding to membership functions μ_A and μ_B respectively, their operations are defined as follows [23]:

II.7.1.Union (OR operator)

$$\mu_{A\cup B}(x) = \mu_A(x) \cup \mu_B(x) = \max(\mu_A(x), \mu_B(x))$$

II.7.2. Intersection (AND operator)

$$\mu_{A\cap B}(x) = \mu_A(x) \cap \mu_B(x) = \min(\mu_A(x), \mu_B(x))$$

II.7.3. Complement (negation or No operator)

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x)$$

II.8.General Structure of Fuzzy Systems

A fuzzy system transforms input data into results through three steps: fuzzification, inference, and defuzzification, evaluating a set of rules.

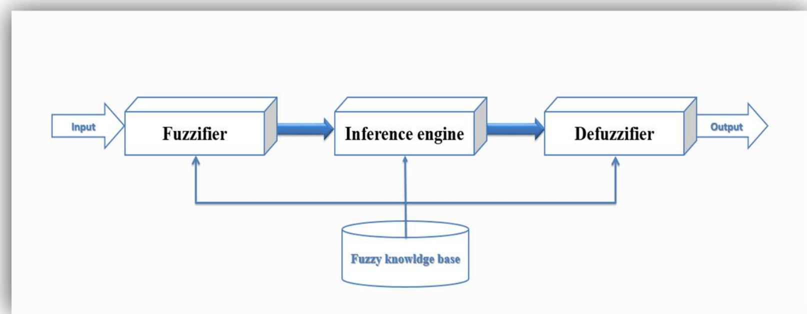


Figure II.15. General Structure of a system based on fuzzy logic.

II.8.1.Fuzzification interface

Fuzzification is the operation of projecting real physical variables onto fuzzy sets characterizing the linguistic values taken by these variables.

The fuzzification block performs the following functions [24]:

- Definition of membership functions of all input variables.
- Transformation of physical quantities (real or digital) to linguistic or fuzzy quantities.

II.8.2.An inference mechanism

The inference system is the main part of fuzzy logic control whose task is decision making. To do this, it uses rules such as ‘IF… THEN’ as well as ‘OR’ or ‘AND’ connectors to establish basic decision rules [25].

II.8.3.Defuzzification

At the end of the inference. The output fuzzy set is determined but it can not be directly used to give precise information to the operator or control an actuator. It is necessary to move from the «fuzzy world» to the «real world», this is defuzzification. There are several defuzzification methods “Centroid of area, Bisector of area, smallest of maximum , largest of maximum”[26]:

II.8.3.1.Centroid principle or Center of Gravity

Sugeno's 1985-developed centroid defuzzification technique, also known as center of gravity or center of area defuzzification, is widely used but is computationally challenging for complex membership functions. The centroid defuzzification technique can be expressed as:

$$z_{CoG} = \frac{\int_z z\,\mu_A(z)\,dz}{\int_z \mu_A(z)\,dz}$$

where z_{CoG} is the crisp output, μA(z) is the aggregated membership function and z is the output variable[27].

II.8.3.2.Bisector Method

The bisector is a vertical line that divides a region into two equal-area sub-regions, sometimes coincident with the centroid line [26].

$$\int_{\alpha}^{z_{BOA}} \mu_A(z)\,dz = \int_{z_{BOA}}^{\beta} \mu_A(z)\,dz$$

II.8.3.2 Largest of Maximum

The largest of maximum is determined by selecting the largest z from [z1, z2] as the crisp value, known as Z_{LOM}[27].

II.8.3.2Smallest of Maximum

The system chooses the smallest output with the maximum membership function, known as the Crisp value Z_{SOM}, from all z in the range [z1, z2][27].

II.9.The Simple Additive Weighting (SAW) method

Is one of best the techniques for resolving the multi-attribute decision-making issue, also known as a weighted summing method[28].Its basic idea is to determine the weighted sum of each alternative on all attributes[29]. The SAW method requires normalizing decision matrix to a scale comparable to all alternative ratings[30].

The steps of the SAW method are presented in **(Figure II.16)**

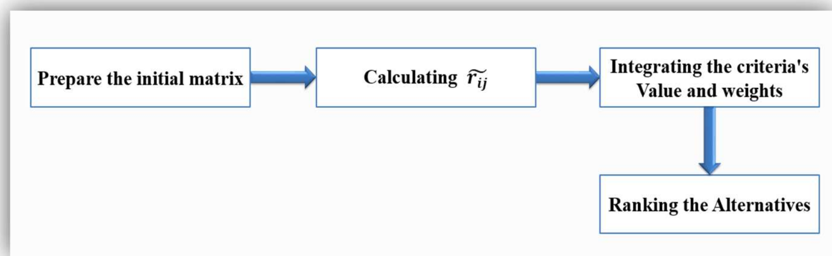


Figure II.16. Steps of the SAW method.

1) Prepare the initial matrix

The initial matrix is created using m criteria and n alternatives, with r_{ij} representing the value of the I criterion for the j object[31].

i=1,2,…,m;

j=1,2,…,n;

The weights of the criteria (w_i) should be determined to indicate their importance, which can be expressed as numbers between zero and one (or by percentages) and considering $\sum_{i=1}^{n} \mathrm{w_i} = 1$.

2) Normalizing the Value of i the Criterion for the j the Alternative (Calculating $\tilde{r}_{ij}$)

The $\tilde{r}_{ij}$ is the normalized criterion's value for the alternative/object, calculated based on the problem type (cost or benefit) and the object's minimization or maximum in cost problems [32].

$$\widetilde{r_{ij}} = \frac{\min r_{ij}}{r_{ij}}$$; if j is a cost attribute.

$$\widetilde{r_{ij}} = \frac{r_{ij}}{\max r_{ij}}$$; if j is a benefit/profit attribute.

Where:

max r_{ij} :is the largest value of the i the criterion when all alternatives are compared.

min r_{ij} :the smallest value of the i the criterion when all alternatives are compared.

3) Integrating the Values of the Criteria and Weights

The integration of criteria and weights yields a single performance value for each alternative For this, the following equation can be used for the j the alternative/ object [32]:

$$S_j = \sum_{i=1}^{n} w_i \widetilde{r_{ij}}$$

4) Ranking the Alternatives to Choose the Best One

The best alternative is selected based on the largest performance value of the S_j maximizing criterion and the smallest for the minimizing criterion [32].

II.10. Service selection in FANETs network with FL_DS

In this work, we propose a new approach called FL-DS (Fuzzy logic decision model), We utilize Mobile Edge Computing (MEC) server in our system to enable the best possible service choices for drone clients. The MEC server allows provider drones to register their services, confirming that the services are available. The MEC server uses FL-DS which is based on fuzzy logic model to determine which UAV services are best for each client. The system automatically switches to requesting cloud computing resources when needed services aren't available locally, guaranteeing continuous service delivery.

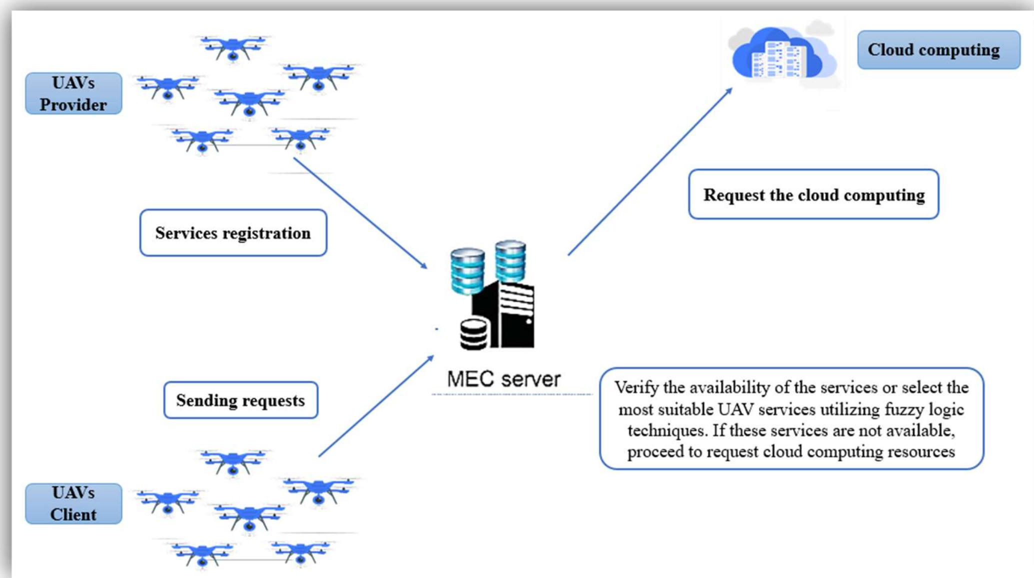


Figure II.17. Architecture of FL-DS.

II.11. Packets exchanged in FL-DS

In FL-DS architecture, drones can act as providers or clients and exchange data packets using User Datagram Protocol (UDP). UDP is lightweight and allows fast and efficient data transfer between drones. UDP applications allow drones to send data packets to each other without establishing a prior connection. When a provider drone wants to offer its resources to other drones, it sends a registration packet to the MEC server. This packet contains information such as the drone ID, the quality of service (QoS) it wants to offer, the price of the service, the packet sending time, the number of packet sending, and the residual energy. When a client drone needs to consume services, it formulates a request packet and sends it to the MEC server. This packet contains information such as the drone ID, the quality of service (QoS) it wants to consume, the price of the service, the packet sending time, the number of packet sending, and the residual energy. When the MEC server receives registration and request packets, it saves all the resources in a UAV cloud directory. If the client and provider drones do not receive a response from the base stations, they continue to send their packets after a certain waiting time When the MEC server receives a request for service from a client drone, it selects a provider drone among the others using a fuzzy logic-based model and also applies another method Simple Additive Weighting.

II.12. Making decision process based on Fuzzy logic

II.12.1. Fuzzification

We shall display the fuzzy representations of the input and output data. The goal of fuzzy logic-based architecture is to determine if each provider drone's (PD) service is qualified to be chosen by the client drones (CD) upon receiving a request from one. To achieve this, we employ thorough fuzzification of variables in our service selection process, including quality criteria as input data: QoS, Qee, Qet, and Qep.

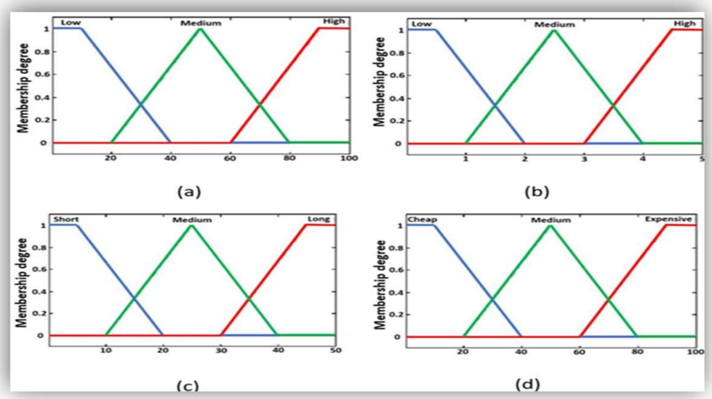


Figure II.18. The membership functions of the linguistic variables: (a) Quality of Service (QoS), (b) Execution energy (Qee), (c) Execution time (Qet) and (d) Execution Price (Qep).

II.12.2. Fuzzy rules definition

We have four input linguistic variables in this fuzzy system, each of which has three fuzzy sets. As a result, 81 fuzzy rules (3^4) have been .Table 1 displays a sit. We then streamlined all of the criteria by giving preference to some language characteristics over others. For instance, we decided that a low quality of service (QoS) would always translate into a bad service, independent of the other variables. This led us to cut the total number of prior regulations to just 54 rules.

Table II.2: Set of rules.

N°	*QoS*	*Qee*	*Qet*	*Qep*	*Service*
1	Low	High	Long	Low	Bad
2	Low	High	Long	Low	Bad
3	Low	High	Short	Low	Bad
4	Low	Low	Long	Low	Bad
5	Low	Low	Long	Low	Bad
⋮	⋮	⋮	⋮	⋮	⋮
30	High	Low	Short	Low	Medium
31	Low	Medium	Medium	Low	Medium
32	High	Low	Long	Low	Medium
⋮	⋮	⋮	⋮	⋮	⋮
80	High	Low	Short	High	Excellent
81	High	Low	Medium	High	Excellent

II.12.3. Deffuzzification

Based on the initial fuzzy set format of the inference output defuzzification produces a precise, non-fuzzy digital output. We apply the center of gravity method in this procedure. example, if the service result is "Medium" (as seen in Fig. 19),we compute the shape of the "Medium" fuzzy set's center of gravity, which comes out to be 0.5.

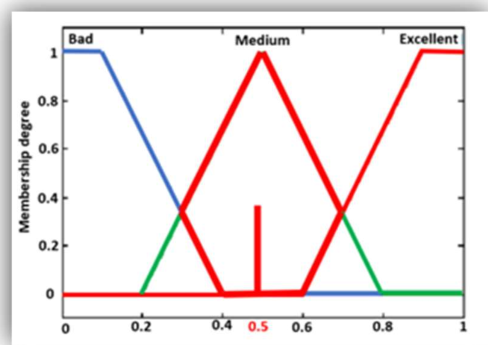


Figure II.19. Defuzzification of the average fuzzy set.

II.13. Making decision process based on Simple Additive Weighting

We have replaced the fuzzy logic technique with an alternative service selection model that takes advantage of multi criteria (the same in FL method) making and is based on the Simple Additive Weighting method (SAW).Note that the criteria are as performance values, and they are numbered from 1 to 4 with:

QoS =1,Qet=2,Qep=3, Qee=4.In each PD, we consider a set of candidate drones

CondidPD = {PD_1, PD_2, PD_3…… PD_n} that leads to get a decision matrix

MATDIC = ($MATDIC_{ij}$; $1 \leq i \leq n$; $1 \leq j \leq 4$).

II.13.1. Normalization

Before combining the performance values, a normalization operation is carried out to obtain a normalized decision matrix that allows all values to be compared.

II.13.2.Performance Score

In our instance, we gave each criterion an equal weight (W_j), meaning that the total of all weights equals one. Next, we multiplied by each criterion's normalized performance values the weight assigned to it. Equation illustrates how we finally summed them for each option to obtain a performance score (PERF), as demonstrated by Equation:

$$\mathbf{PERF(PDi)} = \sum_{\mathbf{j=1}}^{\mathbf{4}} \mathbf{MATDICnormij} * \mathbf{Wj} \text{ where } \sum_{\mathbf{j=1}}^{\mathbf{4}} \mathbf{Wj} = \mathbf{1}$$

Based on the performance score, rankings can be applied to all cloud-based PD services, arranging them in order of highest to lowest quality.

II.14. Conclusion

In this chapter, we discussed the problems involved in the decision-making process in FANET network and proposed a method that helps us choose the appropriate services to meet the needs of users, and we will compare it with Simple additive weighting method. We presented a model based on fuzzy logic for making selection decisions, explained how it works and also explained the basics of SAW. Next, we presented our FL-DS approach explaining how the services provided by the drones are registered in the MEC server and how the proposed model makes the decision. Furthermore, we showed how fuzzy logic can be applied in the context of FL-DS. We have established rules that can determine the quality of service provided by UAVs to users.

Chapter III:
Experimental Analysis

III.1.Introduction

In the previous chapter, after studying the general structure of our project. Now, our proposal was simulated, as we provided a comprehensive guide to preparing and starting to develop it through how to download and install OMNeT++, which is an open source simulator and is used to simulate systems, prepare the integrated development architecture (IDE), as well as download the INET framework, which enables modelling and analysis of protocols. Its harm. In addition to how to start the simulation. Finally, after the simulation parameters began, our proposal was evaluated, then the results were collected and discussed.

III.2.Setting Up and Starting Development with OMNeT++ 4.6 and INET3.2.4

Step 1: Installing OMNeT++

1-Download OMNeT++ 4.6

- Visit the OMNeT++ website at https://omnetpp.org.
- Go to the download section and select OMNeT++ 4.6.

2-Extract the OMNeT++ Files

Unzip the downloaded file to a directory of your choice.

3- Configure OMNeT++

In the MinGW shell that opened, type ./configure. This command will configure OMNeT++ to ensure all necessary components are correctly set up based on your system's configuration.

4-Compile OMNeT++

Still in the MinGW shell, type make. This command compiles the OMNeT++ source code using MinGW's GCC, preparing it for use.

5-Open OMNeT++ IDE

In the same MinGW shell, type omnetpp. This command launches the OMNeT++ IDE where you can start creating and running your simulations.

Step 2: Installing INET Framework

1-Download INET Framework 3.2.4

You can download it from:

https://github.com/inetframework/inet/releases/download/v3.2.4/inet-3.2.4-src.tgz.

2-Extract INET

Unzip the INET framework into the samples directory in your OMNeT++ installation.

3- Import INET into OMNeT++ after that build it

4- Start the simulation

III.3.OMNeT++

Objective Modular Network Test-bed in C++ (OMNeT++)is a discrete event simulator for C++ that may be used to simulate parallel or distributed systems such as communication networks and multiprocessors[33]. Since OMNeT++ is open source, it can be used for free for non-profit purposes under the terms of the Academic Public License [34] .The OMNeT++ it's a simulator written in Object Pascal by dr.GyörgyPongor [35].

OMNeT++ has basic components: C++ simulation kernel library and A simulation integrated development environment (IDE) for the NED topology, description language was created on the Eclipse platform .Runtime interactive GUI for simulation (Qtenv) etc… [36].

The OMNeT++ can be used to simulate for example the following systems: Communication Networks, protocol modelling, validating hardware architectures [35].

III.4.INET

Due to the enormous versatility of OMNeT++, a large variety of pre-built simulation models is available for download. The INET framework is one of them [37]. It also provides an open source-modelling library for the OMNeT++ INET Framework simulation environment for researchers and students working with networking protocols, proxies, and other models. When developing and testing new protocols or investigating new or unusual events, INET is very useful [38].

TCP, UDP, ICMP, IP, PPP, Ethernet, and some routing protocols are among the many implementations of the protocol that make up the INET architecture.

Several protocol-independent modules are also available, including switches, hubs, routers, and routing tables. They are all basic modules that can be combined to create networks and composite modules[37].

III.5.Global Configuration of FL_DS

Network Scenario: This defines a new network type named Scenario. In OMNeT++, a network is a container for modules that can communicate with each other.The scenario is a general simulation of a communications network using unmanned aerial vehicles (UAVs) with sub-modules. Figure1

- **Parameters:** Specifies the "**hosts**" (number of UAVs). And "**numMEC**" (number of MEC Servers).
- **Submodules**
  - radioMedium

Declares a submodule named radioMedium which is of type IdealRadioMedium. This module simulates a simple and idealized radio transmission medium where messages are not subject to interference or signal degradation.

- UAV[hosts]

Declares an array of UAV modules, with the size of the array given by the hosts parameter. Each UAV represents a node in the ad-hoc network.

- MEC[numMEC]

Similar to the UAV module, this line declares an array of MEC modules, sized by the numMEC parameter. Each MEC represents a ground station controller in the network.

- lifecycleController

Adds a lifecycle controller module that can manage the states of other modules (like starting up, shutting down) within the network.

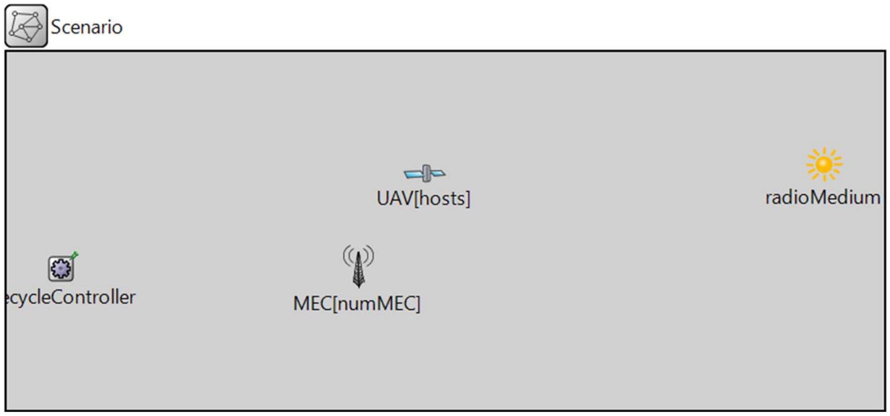


Figure III.20. The "Scenario" network module.

❖ **Configuring omnet.ini**

In the OMNeT++ environment, the omnet.ini file is one of the core files used to adjust simulation settings and define the parameters needed to run simulation experiments. This file contains various configurations, such as network settings, scenario parameters, and simulation run details.

Here are some key configuration parameters and adjustments:

- network = Scenario: Specify which network model to use, linked to the NED file definition
- sim-time-limit = 1000s :Set a limit for simulation time to prevent running indefinitely
- *.hosts = 30: Set the number of UAV hosts in the simulation
- *.numMEC = 1: Set the number of ground station controllers (MEC) in the simulation
- Define the boundaries of the simulation area for movements and interactions:

**.constraintAreaMinX = 0m

**.constraintAreaMinY = 0m

**.constraintAreaMinZ = 0m

**.constraintAreaMaxX = 1000m

**.constraintAreaMaxY = 1000m

**.constraintAreaMaxZ = 1000m

- Set the initial positions of each UAV

*.uav[0].mobility.initialX = 480m

*.uav[0].mobility.initialY = 250m

*.uav[0].mobility.initialZ = 200m

- Only one MEC is used, set its initial position:

*.MEC[0].mobility.initialX = 480m

*.MEC[0].mobility.initialY = 250m

*.MEC[0].mobility.initialZ = 210m

- UAV and MEC Mobility:

**.UAV*.mobilityType = "MassMobility"

**.MEC[0].mobilityType = "MassMobility"

Defines mobility models for UAVs and the MEC using the MassMobility model, which might involve random movements within specified constraints.

UAVs have specific mobility parameters like speed, update interval, and direction change dynamics, indicating dynamic movement throughout the simulation space.

- Communication Settings

*.UAV[*].numUdpApps = 1
*.UAV[*].udpApp[0].typename = "UDPBasicApp"

*.MEC[0].numUdpApps = 1
*.MEC[0].udpApp[0].typename = "UDPBasicApp"

UDPBasicApp: Configures UDP applications on both UAVs and the MEC for sending and receiving messages, including ports, message lengths, and timing for sending.

- Energy Model

**.energyStorageType = "SimpleEnergyStorage"
**.energyConsumerType = "StateBasedEnergyConsumer"
**.energyStorage.nominalCapacity = 100J

Configures an energy model for the UAVs, including energy storage, consumption, and generation, which allows the simulation of power usage and battery life.

III.6.Simulation Parameters

To implement and evaluate FL-DS, **Table III.3** shows all the necessary parameters that were taken in the different simulation scenarios. FL-DS is deployed in a space of 1000m*1000m*1000m. We covered this space with a single MEC Server (Base Station). The density of drones is between 30 drones by taking a case of drone density providers: half of drones.

Table III.3: Simulation parameters.

Parameter	Value
Simulator	OMNeT++4.6
Frameworks	INET 3.2.4
Simulation Time	100s
Simulation Area	1000m×1000m×1000m
Mobility model type	MassMobility
Transmission Range	1000m
Transfer rate	2Mb/s
Data packet size	100Bytes
Application	UDP application
Drones speed	8m/s,20m/s
Number of requested services by client drone	[1-5]
Number of services offered by provider drone	[1-5]

III.7.Application of service selection

III.7.1.Fuzzy logic

After determining the values of the four variables for each UAV provider (QoS - Qee - Qet - Qep).

- We apply the Membership function to the fuzzy logic, this process results in the following figure:

ID	F-QoS	F-Qet	F-Qep	F-Qee
16	1.00	0.67	0.33	1.00
22	0.67	0.67	1.00	0.40
8	0.67	0.67	0.33	0.53
24	0.67	0.67	1.00	1.00
6	0.67	0.67	0.33	0.93
12	1.00	0.67	0.67	0.47
32	1.00	0.67	1.00	1.00
18	0.33	0.67	0.33	0.47
20	1.00	0.67	0.67	0.47
28	0.67	0.67	1.00	0.33
14	1.00	0.67	0.67	0.93
26	1.00	0.67	1.00	0.60
4	1.00	0.67	0.67	0.87
30	0.33	0.67	0.67	0.40
10	1.00	0.67	1.00	0.33

Figure III.21. Fuzzy Results.

- We project the results onto the curve of the previous variables in order to obtain the terms, so previous figure**(Figure III.21)** becomes like this:

ID	F-QoS	F-Qet	F-Qep	F-Qee
16	Medium	Long	Medium	High
22	Low	Long	Cheap	Medium
8	Low	Long	Cheap	Low
24	Low	Long	Medium	High
6	High	Medium	Medium	Medium
12	Low	Long	Medium	Medium
32	Low	Long	Cheap	Medium
18	Medium	Long	Medium	High
20	Low	Short	Medium	Medium
28	High	Medium	Cheap	Low
14	Low	Medium	Cheap	High
26	Low	Short	Medium	Medium
4	High	Medium	Medium	Low
30	Medium	Long	Cheap	High
10	Medium	Short	Cheap	Low

Figure III.22. Fuzzy results terms.

- We define the rule that can be applied to the values of each provider UAV, knowing that the rules have been defined before

ID	F-QoS	F-Qet	F-Qep	F-Qee	Rule
16	Medium	Long	Medium	High	R27
22	Low	Long	Cheap	Medium	R1
8	Low	Long	Cheap	Low	R1
24	Low	Long	Medium	High	R1
6	High	Medium	Medium	Medium	R42
12	Low	Long	Medium	Medium	R1
32	Low	Long	Cheap	Medium	R1
18	Medium	Long	Medium	High	R27
20	Low	Short	Medium	Medium	R1
28	High	Medium	Cheap	Low	R32
14	Low	Medium	Cheap	High	R1
26	Low	Short	Medium	Medium	R1
4	High	Medium	Medium	Low	R33
30	Medium	Long	Cheap	High	R26
10	Medium	Short	Cheap	Low	R2

Figure III.23. Selection of the rules.

- We take the smallest value of the four variables for each provider UAV because we use the fuzzy logic operator **and**

ID	QoS	Qet	Qep	Qee	F_Service
16	1.00	0.67	0.33	1.00	0.33
22	0.67	0.67	1.00	0.40	0.40
8	0.67	0.67	0.33	0.53	0.33
24	0.67	0.67	1.00	1.00	0.67
6	0.67	0.67	0.33	0.93	0.33
12	1.00	0.67	0.67	0.47	0.47
32	1.00	0.67	1.00	1.00	0.67
18	0.33	0.67	0.33	0.47	0.33
20	1.00	0.67	0.67	0.47	0.47
28	0.67	0.67	1.00	0.33	0.33
14	1.00	0.67	0.67	0.93	0.67
26	1.00	0.67	1.00	0.60	0.60
4	1.00	0.67	0.67	0.87	0.67
30	0.33	0.67	0.67	0.40	0.33
10	1.00	0.67	1.00	0.33	0.33

Figure III.24. Fuzzy service value.

- After determining the rule, we apply the center of gravity method of fuzzy service for each UAV provider. We obtain the results shown in the **(Figure III.25)**

ID	F_Service	C_Service	Term_S
16	0.33	0.8	Excellent
22	0.40	0.2	Bad
8	0.33	0.2	Bad
24	0.67	0.2	Bad
6	0.33	0.5	Medium
12	0.47	0.2	Bad
32	0.67	0.2	Bad
18	0.33	0.8	Excellent
20	0.47	0.2	Bad
28	0.33	0.5	Medium
14	0.67	0.2	Bad
26	0.60	0.2	Bad
4	0.67	0.5	Medium
30	0.33	0.8	Excellent
10	0.33	0.2	Bad

Figure III.25. Final results.

III.7.2.Simple Additive Weighting (SAW)

- The first step in the SAW method is to normalize the criteria values so that they can be compared on a similar scale:
  - QoS and Qet were maximized, so their values are divided by their respective maximum values.
  - Qep was minimized, so it was normalized using.
  - Qee was maximized, so its values are also divided by the maximum.

```
********************************
Max QoS (Sto): 90.00
Max QET (Time): 40.00
Min QEP (Cost): 10.00
Max QEE (Energy): 4.90
********************************
```

Figure III.26.max(QoS, Qet, Qee)and min(Qep).

The normalized matrix shows how each provider scored in each category after normalization:

N_Qos	N_Qet	N_Qep	N_Qee
0.556	1.000	0.143	1.000
0.222	1.000	1.000	0.327
0.222	1.000	0.333	0.245
0.222	1.000	0.200	0.980
0.889	0.750	0.143	0.490
0.111	1.000	0.250	0.347
0.111	1.000	1.000	0.510
0.778	1.000	0.143	0.755
0.111	0.250	0.167	0.673
0.889	0.750	1.000	0.306
0.111	0.750	0.500	0.898
0.111	0.250	0.200	0.388
1.000	0.500	0.250	0.143
0.778	1.000	0.500	0.735
0.556	0.250	1.000	0.306

Figure III.27. Normalized Matrix Results.

- The scores for each provider were then calculated by summing the normalized values across all criteria. Here's what stands out:

```
******************************

--- Final Scores ----

******************************
      ID   score
      30   0.753
      28   0.736
      16   0.675
      18   0.669
      32   0.655
      22   0.637
      24   0.600
       6   0.568
      14   0.565
      10   0.528
       4   0.473
       8   0.450
      12   0.427
      20   0.300
      26   0.237
```

Figure III.28. Final Scores and Ranking.

III.8.Results and discussion

III.8.1.Discussion on Fuzzy logic (FL) Method for Service Selection

The initial F_Service scores show considerable variation, reflecting diverse levels of service based on the input parameters. However, the C_Service scores after applying the center of gravity show significant changes:

- «Providers ID 16, 18, and 30» show excellent improvements, moving from relatively lower or moderate initial F_Service scores to high C_Service scores and receiving an "Excellent" rating. This suggests that their combination of service parameters have better energy efficiency combined with decent QoS matches well with what the fuzzy system values for high-quality service.
- « Providers ID 6, 28, and 4»who end up with "Medium" ratings, indicate a balanced but not outstanding combination of parameters. They have reasonable values across the board but lack the exceptional performance in any particular area that would boost them to "Excellent".
- « Most other providers » such as ID 22, 8, 24, and others who received "Bad" ratings, have combinations of parameters that either consistently scored low in crucial areas like QoS or Qee, or failed to compensate for one poor metric with high scores in others.

III.8.2. Simple Additive Weighting (SAW) Method for Service Selection

- **Normalized Matrix Results**
  - Provider 16 has balanced scores in QoS and Qee, which are strong criteria based on their maximum normalization value.
  - Provider 6 has very high QoS but lower scores in other areas, particularly in Qep and Qee.
- **Final Scores and Ranking:**
  - Provider 30 emerged as the top provider, with particularly strong scores in all but Qep, where it was average. This balance across all dimensions likely led to its high score.
  - Provider 28 and Provider 16 follow closely, with strong performances in Qee and QoS respectively, showing that high performance in these criteria can significantly impact overall scores.

The SAW method effectively ranks providers based on a weighted sum of normalized criteria, highlighting which providers are best suited for the clients based on the given weights and values.

Providers with balanced performances across multiple criteria tend to rank higher, suggesting that extremes in one particular area might not be enough unless other areas are also strong.

The choice of normalization (maximizing or minimizing) and the range of actual values greatly influence the final ranking, showing the importance of carefully selecting these parameters in decision-making models like SAW.

III.9.Fuzzy Logic(FL) VS Simple Additive Weighting (SAW)

In evaluating service providers, two methods are particularly useful: Simple Additive Weighting (SAW) and Fuzzy Logic (FL). Each has its strengths and is suited to different decision-making contexts.

SAW ranks providers like ID 30 highest, as they perform well across most criteria, indicating that balanced performance is crucial. In contrast, providers who excel in one area but perform poorly in others may not rank as highly, even if their top performance is critical in specific contexts. This method is best suited for scenarios where decision criteria are independent and where a straightforward, easy-to-understand method is required.

On the other hand, Fuzzy Logic can recognize and enhance providers who possess specific combinations of criteria that are particularly valued. For instance, providers like IDs 16, 18, and

30 excel in both Quality of Service (QoS) and energy efficiency (Qee). This approach suggests a more context-sensitive analysis, which is vital when particular service qualities are more important than others. Fuzzy Logic is preferable in complex environments where different service qualities interact in non-linear ways and where a deeper, more nuanced evaluation is beneficial.

In our system, where the primary goal is to optimize for specific service conditions and effectively handle qualitative nuances, Fuzzy Logic (FL) is the superior choice over Simple Additive Weighting (SAW). FL excels in its ability to provide tailored evaluations based on nuanced criteria, making it particularly effective in settings where service characteristics must interact in complex, non-linear ways. This method ensures that providers who meet specific, critical service conditions are recognized and appropriately ranked, enhancing the overall decision-making process. Conversely, while SAW is advantageous for its straightforward approach and is well suited for general rankings where criteria are independent, it lacks the flexibility and depth required to manage the intricate nuances and specific priorities of our system. Thus, for our needs, FL offers more precise and contextually relevant outcomes.

III.10.Conclusion

In this chapter, we have discussed different steps of the system installation, including the configuration in the OMNeT++, INET working frameworks. We have also presented the FL-DS scenario and another method (SAW) and detailed the simulation parameters used. Then, we proceeded to evaluate our proposal and the other method and discuss the results obtained.

General Conclusion

General Conclusion

Through this study, we used Fuzzy Logic as the main technique for service selection and evaluated its efficacy in comparison to the Simple Additive Weighting (SAW) approach. The aim was to ascertain which methodology best facilitates accurate and adaptable service selection in the inherently dynamic environment of FANETs.

Fuzzy Logic has proven its ability to make complex decisions in FANETs, handling ambiguity and incorporating human-like reasoning. It adapts to fluctuating conditions, providing tailored service selections for enhanced network performance and reliability.

Conversely, The SAW method, known for its straightforward computational approach, is efficient for quick rankings but lacks flexibility to fully capture complex interdependencies and subtle distinctions among service criteria.

The analysis reveals Fuzzy Logic outperforms SAW for general assessments and rankings in complex, variable data environments, enhancing decision accuracy by balancing service quality factors.

Ultimately, the effectiveness of Fuzzy Logic in this context underscores its suitability for applications requiring detailed, context-sensitive decision-making within FANETs. For future implementations and research, Fuzzy Logic stands out as a robust tool for optimizing service selection processes, particularly in advanced network systems where conventional methods fall short in addressing the layered complexities of real-time operational dynamics.

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