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THÈME

Proposition d'un protocole de routage geocast pour les UAVs

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ABSTRACT

Routing in cooperative Unmanned Aerial Vehicles (UAV)s networks is a challenging task due to high mobility of nodes, dynamically changing topology and 3-D movement. In this work, we study the fleet routing problem in Flying Ad-hoc Networks (FANET), which aims at delivering data to a specific group of mobile drones identified by their geographical location. Although many fleet routing protocols have been proposed, only partial inherent constraints of FANET (such as mobility, 3-D movement and reliability) are taken into account. Therefore, we propose a new geocast routing protocol namely Geocast routing protocol for fleet of UAVs (GeoUAVs) designed for satisfying military application. This protocol aims at delivering information to a specific group of mobile UAVs identified by their geographical location. It takes into account the mobility of nodes, dynamic changing topology with 3-D movement, and reliability. Simulations conducted in NS-3 simulator demonstrate that our proposal GeoUAVs outperforms AntHocNet and BeeAdHoc protocols by reducing the average delay and maximizing both the reliability and throughput.

Keywords: FANET, UAVs, fleet routing problem, mobility, GeoUAVs.

RÉSUMÉ

La communication entre flotte de drones (UAVs) ont reçu une attention toute particulière ces dernières années notamment pour des applications millitaires et civiles. En effet, avec l'avènement d'une nouvelle génération de drones, plus petits, plus légers et moins chers, une multitude d'applications ont commencé à utiliser ces flottes de drones pour la protection de l'environnement, l'évaluation des dégâts en cas de catastrophe naturelle (inondations, tremblements de terre,...etc), les applications millitaires concernant la sécurité ou les armées par exemple l'élimination d'une cible.

Une flotte de drones est souvent besoin de collaborer en mode ad-hoc multi-saut pour la transmission de données entre eux afin d'accomplir au mieux les applications précédemment citées. Cependant, une telle collaboration entre drones nécessite l'utilisation d'un protocole de routage répondant aux contraintes de la forte mobilité des drones et aux déconnexions fréquente du réseau. Dans ce contexte, nous nous intéressons au routage multi-saut dans une flotte de drones. L'objectif principal est d'étudier les différents protocols de routage dans cette catégorie afin de proposer une nouvelle solution de routage geocast, répondant aux contraintes des communications inter-UAVs. Les résultats de simulation obtenus à l'aide du simulateur NS-3 ont montré les bonnes performances du nouveau protocole par rapport à d'autres solutions de routage.

Mots clés: UAVs, flotte de drones, routage, forte mobilité, déconnexions fréquente du réseau.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACO Ant Colony Optimization. 23, 24, 25, 26, 28

APAR Ant colony optimization based Polymorphism-Aware Routing algorithm. 24, 27, 28

BCO Bee Colony Optimization. 26, 28

BIMPC Bio-Inspired Mobility Prediction Clustering. 20, 21, 22, 27, 28

EACR Energy Aware Cluster-based Routing. 21, 22, 28

FANET Flying Ad-hoc Networks. 2, 1, 2, 3, 4, 10, 11, 12, 13, 14, 15, 16, 18, 21, 24, 25, 26, 27, 39

GPS Global Positioning System. 12, 16, 22, 30

GS Ground Station. 1, 5

MANET Mobile Ad-hoc Networks. 4, 10, 11, 14, 18

PDR Packed Delivery Ratio. 28

QoS Quality of Service. 26, 28

RGRP-SA Robust Geocast Routing Protocol for Safety Applications. 31

SI Swarm Intelligence. 22

UAANET UAV Ad-hoc NETwork. 4, 10

UAS Unmanned Aircraft System. 5, 8, 9, 8

UAV Unmanned Aerial Vehicles. 2, 1, 2, 3, 4, 5, 6, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 24, 26, 27, 29, 30, 31, 33, 34, 35, 38, 39

URP UAV Routing Protocol. 20, 27, 28

VANET Vehicular Ad-hoc NETworks. 4, 18

WSN Wireless Sensor Network. 20

CHAPTER 1

INTRODUCTION

Contents

1.1 Context and objectives

UAV have recently attracted significant interest in many civilian and military applications such as disaster relief operations, surveillance and reconnaissance, autonomous tracking, managing wildfire, wind estimation, remote sensing, trafic monitoring [3, 4, 5, 6, 7, 8, 9]. To improve the performance of UAVs on their missions, researches are conducted to make UAVs cooperative. A fleet of cooperative UAVs would be able to deal with more complex missions by sharing various task between them. Indeed, assigning different tasks to each UAV, they support each other for a common goal. UAVs can be responsible for the evolution of the operation through the acquisition of new smart behavior. Moreover, the collaboration facilitates the usual tasks and improve performance [10]. This kind of operation requires a high level of coordination between UAVs made possible by a continuous exchange of information among themselves and with their Ground Station (GS). The possibility of using a fleet of UAVs, which may collaborate with each other to offer a cooperative task, defines a new type of ad-hoc network called FANET. Such a network introduces important communication issues, like routing, which is one of the most critical aspects in this context [11].

1.2 Motivations

Recently, the deployment of a fleet of UAVs to pursue a task is enjoying increasing success, since a group of UAVs instead of one single UAV leads to many advantages; for example the possibility to extend the mission coverage, to guarantee a reliable ad-hoc network, or to enhance the operation performance [12].

A network of cooperative UAVs form a FANET, which provides low cost, rapid deployment, and ability to fly above obstacles. However, it also poses many challenges in designing networking protocols such as, the high degree of mobility which causes frequent changes in network topology. That can lead to packet loss, excessive retransmissions and eventually increased delay.

It is important to use a reliable protocol for this kind of networks and check their performance using simulation. This work focuses on the routing protocols that have been used in the fleet of UAVs. There are many routing protocols used in this category of network, which can be classified into two main categories: (i) cluster-oriented routing protocols and (ii) swarm-oriented routing protocols. However, the solutions presented in last two categories respond only to partial challenges in fleet routing for UAVs like high mobility of nodes, dynamically changing topology with 3-D movement and reliability, these protocols need to be modified or a new protocols should be established to adopt this network issues, that is what motivated us to propose new protocol addressing the aforementioned issues.

1.3 Organization of the memoire

This memoire is organized as follows:

- **Chapter two (2)** is meant to introduce the basic concepts of the fleet communication in FANET, such as features, challenges, and at the same time, to provide the main challenges addressed in this work.

- **Chapter three (3)** concerns the state-of-the art and the systematic review of fleet communication in FANET, it illustrates the different fleet routing protocols in FANET with a detailed synthesizing and comparison of all discussed protocols.
- **Chapter four (4)** presents our novel geocast routing protocol, designed for fleet of UAVs in FANET.
- Finally, we conclude the work with a conclusion that summarizes our work and gives some future perspectives.

CHAPTER 2

FLYING AD-HOC NETWORKS: A BIRD'S VIEW

Contents

2.1 Introduction

The use of UAVs increases day by day in various areas like military and civilian applications. Thus, there existe numerous attempts to insure better preformance. Therefore, small group of UAVs is used instead of single UAV. However, there are some issues concerning the communication between UAVs. So, multi UAV systems are necessary to create an network between the UAVs which is known as FANET or UAV Ad-hoc NETwork (UAANET). FANET is basically a special form of Mobile Ad-hoc

Networks (MANET)/Vehicular Ad-hoc NETworks (VANET). However, there are also many differences between FANET and other ad-hoc networks such as the mobility degree and the power needed [13].

This chapter deals with Unmanned Aircraft System (definition, architecture, and classification), presents flying ad-hoc networks (characteristics, applications, challenges, and architectures). Communications in fleet of UAVs are also presented in this chapter.

2.2 Unmanned Aircraft System (UAS)

A Unmanned Aircraft System (UAS) is a system composed of UAVs, communication links, ground control station, a launch and recovery system, and any other system elements that may be required during flight operation. Although the International Civil Aviation Organization (ICAO) advises using the term Remotely Piloted Aircraft System (RPAS) [14], the literature quotes many other terms to designate such a heterogeneous system. For the sake of clarity, Table 2.1 summarizes these terms:

Given name	Meaning
UAS	Unmanned Aircraft System
UAV System	Unmanned Aerial Vehicle System
RPAS	Remotely Piloted Aircraft System
RPV System	Remotely Piloted Vehicle System

Table 2.1: Different terms used to indicate UAS.

The architecture of a typical UAS is show in Figure 2.1 [14].

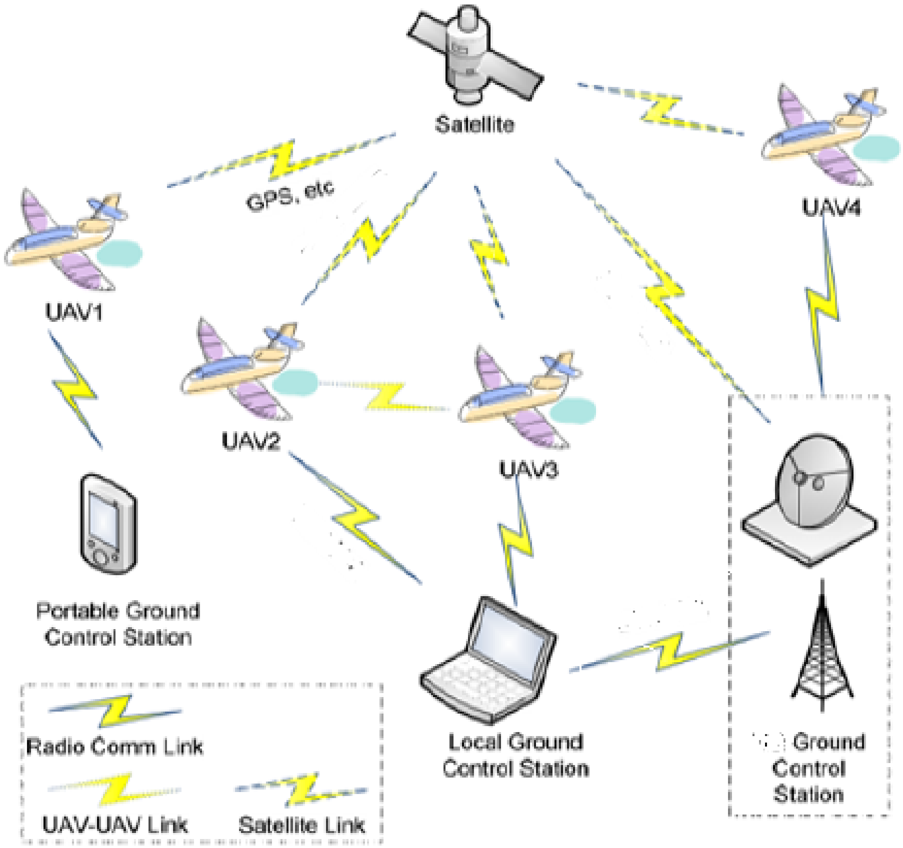

Figure 2.1: Example of UAS architecture.

2.2.1 Unmanned Aerial Vehicle

The main component of a UAS is the UAV (or drone[1]) which can be remotely controlled or fly autonomously based on a preprogramed or predetermined flight plan. It is usually required to fly out of sight of the operator and be able to communicate in real time with the controller sending back the payload data. It must also periodically return information about its flight conditions (e.g. position, speed, heading or altitude) to the GS. This data helps the operator to evaluate the flight conditions and accordingly if needed, allows it to modify the flight settings. In addition, some UAVs may also be equipped with on-board decision-making capabilities to support automatic corrective responses in case of component failures.

It is important to emphasize the existence of several kinds of UAVs, each one de-

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[1] We use the terms 'UAV', 'drone', and 'node' interchangeably in the rest of the memoire.

signed for a different purpose. It is possible to categorize them in many ways using different metrics (e.g., size, shape, autonomy, operational altitude, operating conditions and certification approaches). UAV classification is important from a regulatory perspective as different requirements may be imposed on UAV categories according to their features [15].

-Components

UAV is mainly composed of three major parties (cf., Fig 2.2) [1]:

1. The **chassis** : (or frame) is a bit like the skeleton of the drone. It takes different forms based on the model and the number of arms, in addition there exist tricopter drones quadcopter, hexacopter,...etc. of aluminum, plastic, carbon fiber or even wood, the chassis can truly vary-depending on the drone models.

2. The **propulsion system**: it is composed of motors namely rotors, helices, and Electric Speed Controller (ESC), plus a Lipo batterie (Lithium polymer).

3. The **flight controller**: it creates the link between the pilot and the drone via connected receiver, thanks to an integrated circuit inside a microprocessor, sensors, and an in/out broaches.

-Classification

Classification of drones is a very difficult exercise, as it differs from country to another. However, the drones can be classified according to three criteria [16]:

- Tactical drones.
- UAVs of Medium Altitude and Long Endurance (MALE) to use a payload of the order of 100 kg.

Figure 2.2: Unmanned Aerial Vehicle (UAV) [1].

- High Altitude and Long Endurance (HALE) drones.

The tactical segment is divided into six segments:

- Micro-drones (Micro Air Vehicles or MAVs), which can be contained in a sphere of 30 cm.
- Mini-drones (Mini Air Vehicle or MAV also), which can be contained in a sphere of 70 cm.
- Very short range drones.
- Slow mid-range UAVs.
- Low altitude fast drones.
- Tactical Maritime Drones (DMT).

2.2.2 Payload

Each UAV usually carries a payload [2], which is the most significant part of the UAS since it is the ultimate reason for having such a system. It should be noted that in order to deploy a payload for small UAVs, a trade-off between communications, power, sensors and autopilot subsystems must be found so that the overall UAV system balance of weight and volume is preserved. Typically, the payload used in civilian UAVs is a digital camera that streams or records a video (for reconnaissance and surveillance missions). It should be noted that in this case, the digital camera must be placed under the front of the UAV in order to detect any obstacle during the landing phase. Depending on the UAV size and the application requirements, the traffic payload is then sent to the Ground Control Station (GCS). The payload may also be a special sensor used to collect samples or gather information related to a specific field (e.g. a temperature sensor). Another type of UAV payload is a communication platform device for data and communications. In this case, the objective is to extend the coverage of the radio frequency systems, including the set of data links used to exchange payload and control traffic [14].

2.2.3 Ground Control Station

A GCS is a combination of multiple entities that form an independent infrastructure to monitor UAV movements. It allows the operator to adjust way-points, flight paths, altitude, air speed and landing zones. The GCS communicates with UAVs through the communication system up-link and waits for information in return on the down link. Typically, a GCS is composed of the following two entities [14]:

1. **GCS Desktop software:** This is one of the crucial parts of the UAS. The software allows the operator to control the UAVs during all the flight phases and to analyze the features of the surrounding zones in order to give a predictive

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[2] In order to avoid misunderstanding, it should be noted that the payload from an UAS point of view is quite different from the payload traffic, which is the amount of additional data required by traffic control.

signal strength map. It also enables the operator to monitor and adjust sensor payloads during UAV missions.

2. **GCS infrastructure:** The physical part of the GCS. It includes a transmitter to transmit and receive data traffic respectively. This infrastructure supports communication between the GCS and the nearest UAV through a two-way communication link: the up-link provides control of the UAV flight and commands for its payload, whereas the down link provides acknowledgments to (air) traffic control and transmits UAV status information (e.g. altitude, speed, direction, etc.). Furthermore, in order to be sure of the effectiveness of the mission, it is desirable that the data link provides an anti-interference capability.

2.3 Flying Ad-hoc Networks

The drones' Ad-Hoc Network (FANET or UAANET) define a new form of MANET where the nodes are drones that allow the transmission of the messages towards their destinations. Recent studies have been done and lead to the creation of a system of multi-cooperative drones, where many drones co-work with each other to achieve a mission in high performance [17].

The drones cooperate with each other and with the Ground Station(s) for routing and data exchange purposes as shown in Figure 2.3 [18].

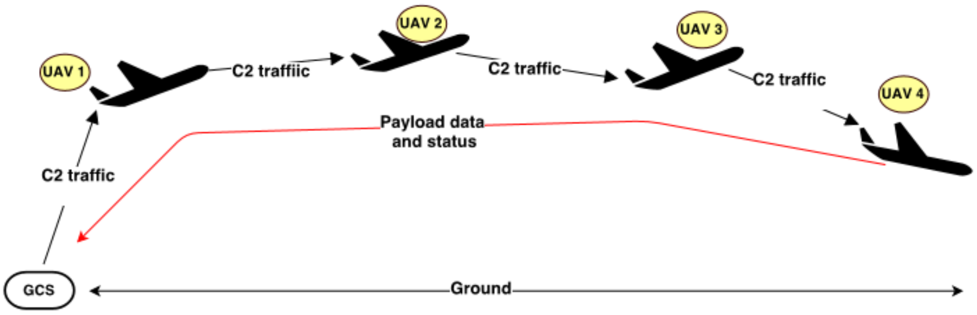


Figure 2.3: Flying Ad-hoc Networks

2.3.1 FANET features

In FANET and MANET, there are many common design considerations. FANET is characterized by different features, the main of which are [13, 19]:

- **Node Mobility**

  The UAV has a speed of 30-460 km/h, and this speed causes the communication problem between UAVs .

- **Mobility Models**

  In many mobility models, the flight plan is predetermined and at each step there is a change, recalculation for the map take place. Other models are using random speed and directions for the UAVs.

- **Node Density**

  The average number of UAVs in some area is called Node Density. In FANET, it must be a sparse density with large distances between them according to the nature of flying.

- **Network Topology**

  In order to the higher mobility, degree, topology changed frequently. The communication between UAVs has also broken frequently, because the higher speed, or if the UAV is out of the range because location changing occurs rapidly. At each UAV connection failure, update processing is needed.

- **Radio Propagation model**

  Here, according to the nature of the environment in FANET and the large distances between UAVs. The UAVs uses a line-of-sight between them and with a ground base. In contrast with MANET, it does not use any radio signal between nodes.

- **Power Consumption and network lifetime**

  Network lifetime is an important issue for the network, which consists of battery-powered computing devices. Communication hardware used in FANET is powered by UAV energy source itself. In case of this, FANET designs may not be power sensitive, in contrast with MANET applications. But it stills a problem in mini UAVs.

- **Localization**

  Localization means determining the location for each UAV. According to high speed and frequently change in place, there is a need for highly localization information with small intervals of time. Using Global Positioning System (GPS), the information about the new locations will be propagated to the network each one second, and this is not sufficient. Therefore, each UAV must be containing a GPS and Initial measurement unit to broadcast his location to all UAVs in the network at any time.

The comparison of Ad-hoc Network types is given in Table 2.2 [2].

Criteria	Ad-hoc network types		
	FANET	VANET	MANET
Node mobility	High compactness	Medium compactness	Low compactness
Mobility model	Usually predetermined, but special mobility models for independent multi-UAV systems	Steady	Arbitrary
Node density	Low density	Medium density	Low density
Topology change	Rapid and speedy	Average speed	Slow and steady
Radio propagation model	High above the ground Level, LoS (Line of Sight) is accessible for most of the cases	Close to ground, now accessible for all cases	LoS is not accessible for all cases
Power consumption and network lifetime	Needed for mini UAVs, but now needed for small UAVs	Not needed	Needed of energy efficient protocols
Computational power	Very high	Average	Limited
Localization	GPS, AGPS, DGPS, IMU	GPS, AGPS, DGPS	GPS

Table 2.2: Comparison of FANET, VANET and MANET [2].

2.3.2 FANET applications

Due to various advantages and wide range of application areas FANET are getting attention of research community around the globe [20].

- **Military Services:** There are very useful in military services. Setting up proper communication system is very difficult in military areas. So they are used for information exchange between soldiers, and military headquarters.
- **Security Purpose:** They are capable of receiving information quickly. It can be used to collect information for the security purpose of a delegate visiting to a place where no network infrastructure exists.
- **Search and Rescue Operations:** It can be used provide a better way to do search and rescue operations such as rescue operation of hostages. Some times in extreme situations, cellular networks get damaged. FANET provide better rescue services in such conditions by sending periodic updates to other locations.
- **In Sensor Networks:** Different sensor devices can be used to collect data to do daily functions like weather forecasting, terrestrial movement tracking etc. FANET can approach to any remote location without difficulties.

2.3.3 FANET communication architectures

Communication architectures in FANET comprises the following schemes [18]:

(1) Centralized architecture

The centralized communication architecture for FANET is characterized by a direct link between the centralized node (eg: Ground Station) and the UAVs exist in entourage. In this architecture each UAV connects directly with the Groud Station for exchanging data (sending the data of payload and receiving control and command traffic). The ground Station is the relay node for exchanging the information between adjacent UAVs, because of the absence of Inter-connection among UAVs.

(2) Architecture through satellite

In this architecture the satellite is the relay for communication, its receptive antennas receive the signal from the ground station. there are two types of satellite: geostationary satellite and astronomical satellite. The geostationary satellite is situated in the equatorial plan. It rotates with the same speed and the same sense of the earth; its trajectory is fixed depending on a spot in the earth. The second one covers the different geographical zones.

(3) Cellular based architecture

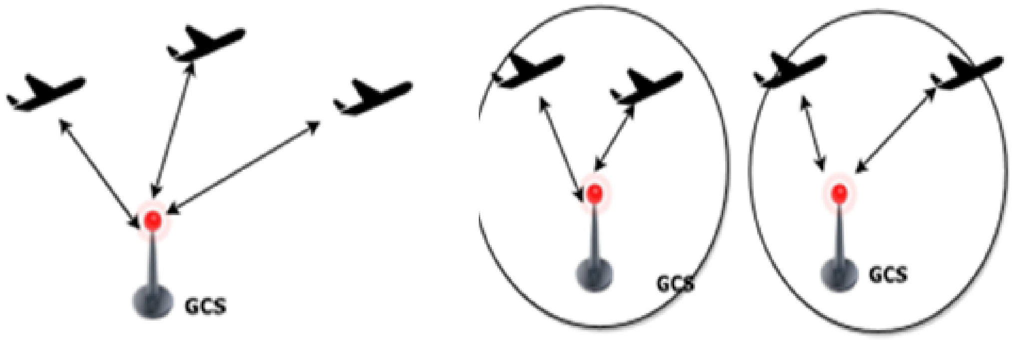
This architecture is used in the telephonic domain. It is based on the use of a base station infrastructure, which forms multiple cellular beams where one or multiple UAVs are located. In each cell there is a ground station for generating the group (of UAVs), the connection inter-group necessitate to pass with the ground station, and it possible for two drones to communicate through the base station.

(4) Communication Ad-hoc architecture

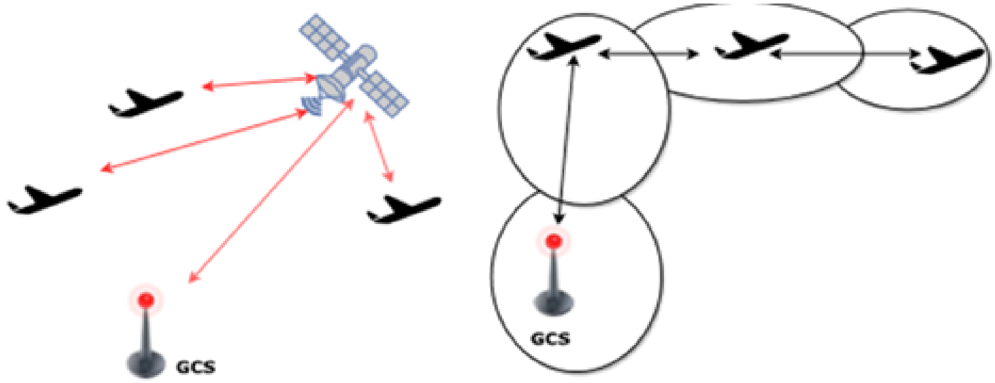
An ad-hoc network is characterized by a set of potentially mobile entities with one or more radio interfaces that set up a short term communication network according to the needs of the application. These nodes can be brought in or out of the network at any time. The ad-hoc network is decentralized and ready for self-organization without the need for a fixed infrastructure. If transmitter is not in direct reach of the destination machine, the infrastructure is transmitted step by step, along a path established and maintained by the network in case of the modification of topology. Unlike the traditional wireless network, the service area of the network is the geographical area in which the nodes are distributed.

Ad-hoc wireless network allows communication between two nodes that are out of direct reach of each other.

An illustration of Communication architectures for FANET is shown in Figure 2.4.



(a) Centralized architecture (b) Cellular architecture



(c) Architecture through Satellite (d) Ad Hoc architecture

Figure 2.4: Communication modes for FANET.

2.3.4 FANET challenges

Being a member of MANET family, FANET faces the same challenges in MANET in addition to other challenges resulted from its high node speed, high topology changes and mobility models [20].

- **Routing:** Routing in FANET is different from other ad-hoc networks family. Node movement is relatively very high in this category. So, the topology changes very frequently. One of the biggest challenges is to develop an efficient routing algorithm that are not only able to work with high mobility nodes but should also be quick to update its routing table frequently as the topology changes.

- **Security:** Ensuring confidentiality, availability and Integrity of information during the communication between UAV to UAV communication and UAV to ground node communication is one of the major issues in FANET. Due to lack of physical security node compromise becomes easy in it. Trust Management among nodes is another challenge due to high topology changes. Nodes join and leave the network very frequently.

- **QoS (Quality of Service):** In FANET, UAVs transmit data including audio, video, images, text, GPS locations,... etc. To transfer such data it should have a good quality of service with less delays and error rates. In addition, the reliability of the network should be very high.
- **UAV Mobility and Placement:** The placement of UAVs at an appropriate location is one of the major research concerns in FANET. UAVs of different capacity and capability are used for different purpose. Mini-UAVs are meant for carrying fewer payloads, like a thermal camera, single radar, camera, image sensor, ...etc. So, this is an open challenge to optimize the UAV placement to diminish energy feeding when the retrieved information is taking more time.

2.4 Fleet of UAVs

It is a cooperative group of drones that share and distribute missions among each other to achieve a complex tasks.

Using a fleet of drones to accomplish a certain mission have witnessed an increasing positive result, since using a group of UAVs instead of a single one provide many advantages [18]:

- **Cost:** It is cheaper to use group of small UAVs than to use one big UAV, plus it provides a lower maintenance.
- **Latency:** When muti-UAVs are used to execute a mission, the time needed will be optimized.
- **Scalability:** A single UAV can cover only a limited zone for a limited time. this problem can be solved when replacing one UAV with a fleet, because the latter can figure out solutions for the possible obstacles and enlarge the covered zone.

- **Sustainability:** The mission can still survive when a fleet is responsible for the work even if one drone is down. Due to the existence of other drones to do the job.

2.5 Conclusion

In this chapter, we have provided a background on the use of UAVs in wireless networks, we have explored key characteristics, applications, challenges, and communication architectures. Moreover, we have presented fundamental benefits for using drones' fleet. The following chapter describes the major state of the art pertaining to the fleet of UAVs.

CHAPTER 3

FLEET ROUTING PROTOCOLS FOR UAVS: RELATED WORKS

Contents

3.1 Introduction

FANET is recently the topic of interest of many researchers. On the attempt of updating this filed and due the fact that FANET differs from MANET/VANET, this lead the creation of a new protocols and the improvement of others to suit the FANET.

Along with this chapter, we will be presenting the existing fleet routing protocols for UAVs with a detailed synthesizing and comparison of all discussed protocols.

3.2 Taxonomy of fleet routing protocols for UAVs

In the literature, many fleet routing protocols exist in MANET and VANET, which have been suggested for FANET in order to establish an efficient and reliable communication among the cooperative UAVs. However, due to the UAVs explicit characteristics, such as high mobility in the 3D space, most of these routing protocols cannot directly applied for UAVs. For this reason, some traditional routing protocols have been modified and some new ones have been implemented for FANET. These protocols are broadly placed into two main categories: (i) cluster-oriented routing protocols and (ii) swarm-oriented routing protocols as shown in Fig.3.1.

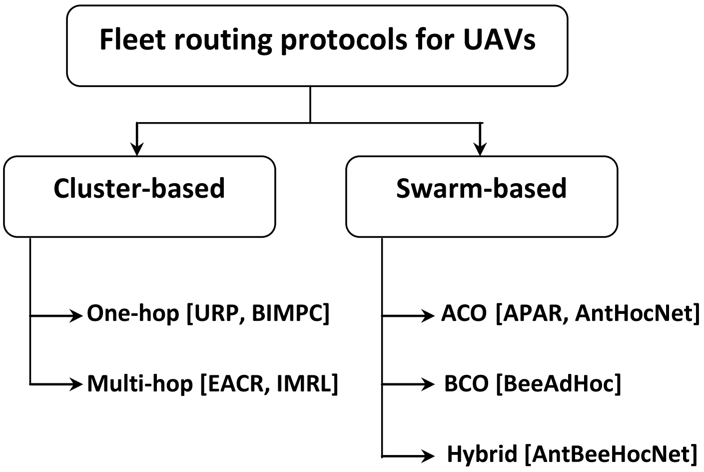


Figure 3.1: Classification of the routing protocols in fleet of UAVs.

3.2.1 Cluster-based protocols

Clustering is an approach for arranging nodes having same geographical neighborhood, into multiple groups. It provides multiple advantages such as scalability, reliability, fault tolerance, data aggregation, energy efficiency, coverage, connectivity, and reduced delay [21].

In cluster-oriented routing protocols the nodes of a wireless network are divided into several disjoint or overlapping clusters. Each cluster elects one node as the head which is called the cluster-head. The cluster-heads are responsible for the routing process.

Cluster-heads are able to communicate with each other using cluster-gateway. In terms of cluster formation, clustering schemes can be classified into two main categories: (i) one-hop clustering and (ii) multi-hop clustering, indicating the maximum number of hops from a cluster-head to its farthest cluster-member [22].

Many clustering algorithms are based on one-hop communication in which the cluster-member is one-hop away from its cluster-head [23, 24, 25]. For instance,

(i) Uddin et al. [23] proposed a UAV-assisted dynamic clustering named UAV Routing Protocol (URP) for crop health monitoring. URP is a dynamic cluster-oriented routing protocol that aims at collecting data from a selected area. In this work, a UAV-based mobile sink node collects data from scattered nodes based on a random walk or predefined path. A UAV sends a beacon message to activate all sensor nodes residing in its neighbors, and it makes a cluster by considering path and data type.

   The nodes in this protocol are grouped into three types which are cluster members (CMs), candidate clusters (CCs), and candidate cluster heads (CCHs). Both, the CCHs and the UAV, are collectively taking part in the selection process to nominate a node as CH. The dynamic clustering scheme in URP is illustrated in Fig 3.2 [1].

   The participation of each node in the CH election process is determined by the calculation of its probability, through out the use of the Bayesian classifier.

   - Advantages: URP can be used in a quickly deployed UAV network without any existing infrastructure.
   - Limitations: URP is designed only for Wireless Sensor Network (WSN) assisted with a UAV using a single-hop transmission which cannot extended to a multi-hop transmission scheme.

(ii) In [24], Bio-Inspired Mobility Prediction Clustering (BIMPC) protocol is proposed. BIMPC combines the mobility of UAV and transplants the foraging model of physarum polycephalum to the field of ad-hoc UAV networks. It is assumed

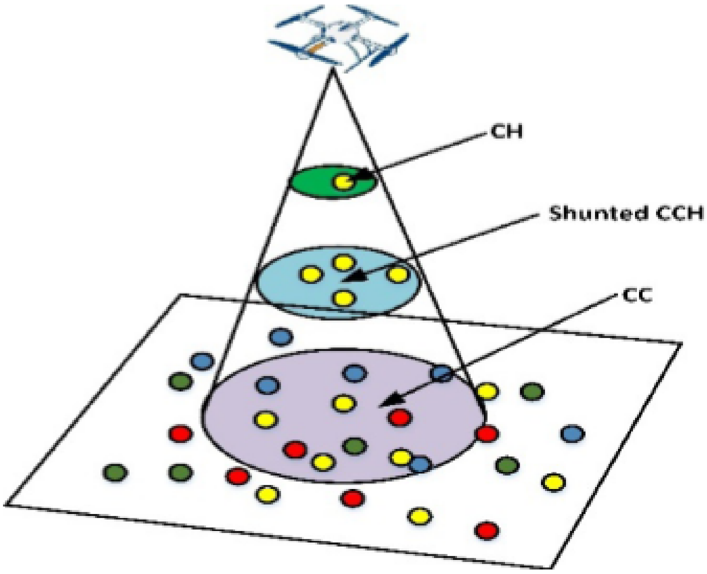


Figure 3.2: Dynamic clustering scheme in URP.

that the current UAV may calculate the sum of the value of one-hop neighbors and stability of the established cluster.

- Advantages: The simulation results of BIMPC show a better performance in cluster formation and maintenance of highly dynamic clustering in large-scale UAV networks.
- Limitations: The BIMPC routing protocol only considers UAV nodes with moderate mobility [25].

Small coverage of one-hop clusters leads to an increase in the number of cluster-heads. This can decrease routing efficiency and raise communication cost when communication beyond the cluster small range is necessary.

Multi-hop clustering protocols extend the communication coverage in the same cluster and reduce the number of cluster-heads and subsequently the number of clusters. Most of recent researches are focusing on multi-hop communication [26, 27, 28]. For instance,

(i) Aadil et al. [26] proposed the Energy Aware Cluster-based Routing (EACR) protocol for FANET. EACR aims to address two major problems in UAV routing such as limited battery energy and the mobility of UAV. To resolve both problems, the authors adjusted the transmission power of the UAV by anticipating their operational requirements. Optimal transmission range will have minimum Packet Loss Ratio (PLR) and better link quality, which ultimately save the energy consumed during communication. Second, they used a variant of the K-Means Density clustering algorithm for selection of cluster heads. Optimal cluster heads enhance the cluster lifetime and reduce the routing overhead.

- Advantages: EACR minimizes energy by controlling the transmission range and optimizes the routing calculation.
- Limitations: The EACR protocol only considers UAV nodes with moderate mobility same as BIMPC.

(ii) Khelifi et al. [27] proposed a fuzzy-based cluster routing algorithm called IMRL, IMRL relies on a weighted centroid localization technique, where UAV nodes positions are calculated using fuzzy logic. The UAV nodes are organized into clusters. The proposed localization algorithm first localizes the UAVs, then elects the next cluster head in order to minimize the energy consumption of the whole network and consequently increase its lifetime.

- Advantages: IMRL routing protocol can be effectively used in bad weather when GPS signal could be totally absent or insufficient due to multi-path fading and jamming.
- Limitations: High latency of transmission and cost of launching the satellite are the major drawbacks of IMRL routing protocol [25].

Compared to one-hop clustering schemes: On one hand, a multi-hop clustering scheme can delivered good scalability for large networks but network delays and overhead are experienced when forming clusters in highly mobile UAVs. On the other hand, a multi-hop clustering scheme requires more beacon exchanges within the maximum number of hops, which may cause the increase in the number of connections lost and longer cluster formation time [22].

3.2.2 Swarm-based protocols

Self-organization and complex behavior occur in multi-agent systems, even if each agent has a rather simple behavior strategy. It underlies the so-called "Swarm Intelligence (SI)" [29]. The SI is a distributed and self-organized system which considered as an optimization algorithm in Artificial Intelligence. The implementation of SI is based on swarm algorithms. To realize this kind of algorithms, the social behaviors of birds or fishes in flocks or ant colonies on swarm are modeled. These can be the suitable solution for complex optimization problems. These algorithms aim at finding a near-optimal solution for the target mission [30, 31]. As swarm-based routing protocols, which are dedicated for cooperative UAVs, can be classified into two main categories: (i) ant colony optimization-based and (ii) bee colony optimization-based.

(1) Ant Colony Optimization-based

Ant Colony Optimization (ACO) is an evolutionary method suitable for solving combinatorial optimization problems. It belongs to the so called meta-heuristic methods for optimization. In meta-heuristic algorithms, values of several algorithm components and parameters have to be set, due to their significant impact on the algorithm's efficacy and performance. Therefore, it is important to study how the algorithm parameters affect the performance [32].

The ant algorithms differ from the traditional ones. The hybrid algorithms, including reactive and proactive components, provide the best results.

The reactive component is performed only on demand and reacts to the events requiring the algorithm usage, namely, the information acquisition on destination sites involved in the communication session. This can be compared to the process of food search performed by an ant in natural environment.

The proactive component operates periodically. Its function is to maintain and improve the connection and to update the information about the existing routes during the communication session. The reactive component differs from the proactive one since it operates only when the existing known routes become faulty (come out of action). This is similar to the way improvement between the ant the food source in nature.

Pheromone tables store the routing information. These tables are represented as distance-vector two-dimensional matrices. The pheromones in nature perform the same function. With these tables, the control packets and data forwarding occurs stochastically (cf,. Fig 3.3). The given network node has neighboring nodes X, Y and Z, while all network nodes act as destination ones. The network includes N nodes.

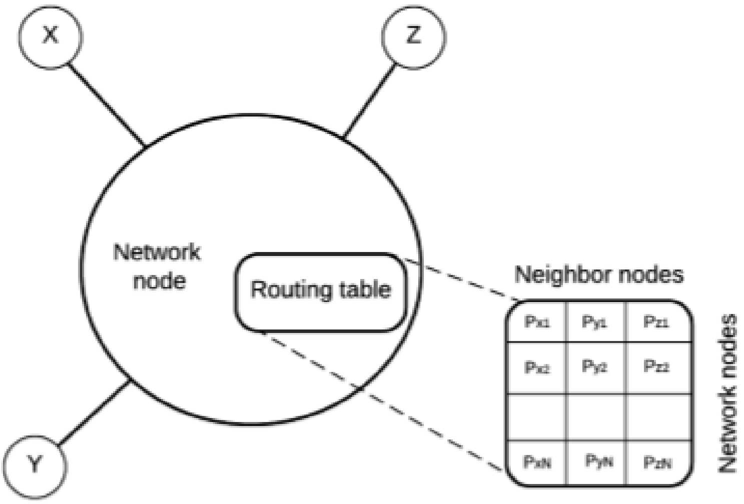


Figure 3.3: The node routing information is stored in pheromone table.

Some ACO routing protocols are proposed for FANET [33, 34]. For instance,

(i) Yu et al. proposed a meta-heuristic algorithm called Ant colony optimization based Polymorphism-Aware Routing algorithm (APAR) [33]. APAR integrates the ACO algorithm to detect the network congestion degree, judges the stability between nodes and neighbors according to the received signal power. Nodes with high mobility in the cache were deleted according to the node stability and the congestion degree.

  - Advantages: APAR effectively avoids congestion and link breakage by establishing standards to choose routes based on sensing the distance of a route, the stability of a route and the congestion level of a route. In addition, the simulation results show that APAR algorithm can ensure lower average end-to-end delay, routing overhead and higher data packet delivery ratio.

- Limitations: This method cannot overcome the high mobility of UAVs.

(ii) Maistrenko et al. [34] used the ACO algorithm to develop AntHocNet protocol for solving the high mobility problem in FANET. The simulation outcomes show that this routing protocol gives better performance for packet delivery and delay compared to contemporaries solutions.

- Advantages: According to experiment AntHocNet protocol is more preferable for FANET with high mobility of nodes.
- Limitations: Using ACO algorithm is less effective because of high costs for routing service information transfer [34].

(2) Bee Colony Optimization-based

When observing bee colonies, the scientists noticed some interesting features proved to be useful for solving routing problems in wireless ad-hoc networks [35].

In Bee routing Algorithms, The first stage is called ”scouting”, divided into forward and backward scouting. Forward scouts inspect the network, looking for the head-end presence. They carry four categories of information. They are the scout ID (Identification Number), the source node ID, minimal residual energy (initially equal to infinity), and the number of hops (initially equal to zero). The scouts are sent to all source node neighborhoods and so on. Upon arriving at another intermediate node, the counter of hops number is increased by 1. Once the destination node is found, the backward scout returns to the source node, and multiple channels are created between the source and head-end [29].

The algorithm checks the scout characteristics at each visited node, and thus draws a conclusion on the route efficiency. It is a rather complicated procedure, and it includes several verification steps.

When the scouting procedure is completed and the route is determined, “dance formula” is used to calculate the number of forager-bees necessary for the route.

Then, another stage begins, known as ”resource foraging”. The foragers transfer the data in a way, similar to the real bees transporting the food.

Data transmission process is rather complicated as well. The data are transmitted from the source node to the destination one, while the number of forager-bees may vary. The probability distribution table is employed for probabilistic calculation.

The intermediate nodes making no decisions on routing is the main difference from the ant colony optimization algorithm, since all decisions come from the source node. In ACO algorithm each intermediate node contains the pheromone tables. The calculations on the network operation improvement and the decisions are also made in such nodes.

To return to the source node, the foragers should merge in a single swarm. This merge takes place on the same ID of the foragers' route. The routes number is determined during the comeback, and inefficient routes are removed from the routing tables.

The analysis of routing protocols of FANET based on Bee Colony Optimization (BCO) is done by the following works [35, 36]. Leonov et al. [35] proposed a swarm-based routing algorithm called BeeAdHoc. The authors of this work explain the routing process in a swarm of UAVs based on the bee colony optimization algorithm. In [36], a hybrid algorithm called AntBeeHocNet. AntBeeHocNet is based on the ant (AntHocNet) and bee (BeeAdHoc) colony algorithms for solving the routing problems in FANET.

- Advantages: The simulation results show that BeeAdHoc and AntBeeHocNet give more effective results than traditional FANET routing algorithms in most cases.
- Limitations: Because these protocols use the same ACO algorithm with AntHocNet, thus, they have the same drawbacks as AntHocNet.

3.3 Comparison and summary

This section presents the comparative study as emerged from the protocols above. In Table 3.1, we compare the existing fleet routing protocols in FANET based on the following criteria: communication type, routing strategy and Quality of Service (QoS) requirements.

This study is concerning both cluster-based protocols and swarm-based protocols. The cluster-based protocols hold various advantages, This better illustrated in:

Concerning one hope clustering protocols, the URP can be utilized in quickly deployed UAV network without any existing infrastructure. In addition, BIMPC provides a better performance in cluster formation. However, the small coverage of one-hop cluster causes the increase of the number of cluster heads, witch leads to the raise of the communication costs.

The multi-hope clustering protocols enlarge the communication coverage and reduces the number of cluster heads. Nonetheless, the cluster-oriented protocols have some disadvantages, the widely common: They only consider UAVs nodes with moderate mobility, and the high latency of transmission.

As for the swarm-oriented protocols, they are classified into two main categories: (i) ant colony optimization-based and (ii) bee colony optimization-based, one of the proposed algorithm in the first category is APAR, it effectively avoids congestion and link breakage. In addition, according to the simulation results of the second category, give more effective results than the traditional FANET routing algorithms. However, The swarm-oriented protocols have a problem of struggling with the calculation especially, the reliability and the delay for maintaining their communication structures. Furthermore, they cannot overcome the high mobility of UAVs. Thus, it is critical to design a new protocol addressing the aforementioned issues. Thus we have attempted to figure out a new protocol that is based upon the geocast routing as a solution to those issues named GeoUAVs. The following chapter describes the details of our new solution.

Table 3.1: Classifications of fleet routing protocols for UAVs; S: Single, M: Multi.

	Communication Type		Routing Strategy					Other Criteria						QoS-parameter		
	UAV-to-WSN	UAV-to-UAV	Cluster-based		Swarm-based			3D Communication	Energy awareness	Scalability	Centralized/Distributed	Average Network Partitioning	Simulator	Packed Delivery Ratio (PDR)	Minimization Delay	Throughput
Protocols			S-Hop	M-Hop	ACO	BCO	Geocast									
URP: [23]	✓	✗	✓	✗	✗	✗	✗	✗	✓	✗	Distributed	✗	Matlab	✗	✓	✗
BIMPC:[24]	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	Distributed	✗	Matlab	✓	✓	✗
EACR:[26]	✗	✓	✗	✓	✗	✗	✗	✗	✓	✓	Distributed	✓	NS-2	✓	✓	✓
IMRL: [27]	✗	✓	✗	✓	✗	✗	✗	✗	✓	✓	Centralized	✓	Matlab	✓	✓	✓
APAR: [33]	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	Centralized	✓	NS-2	✓	✓	✗
AntHocNet: [34]	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	Centralized	✓	NS-2	✓	✓	✗
BeeAdHoc: [35]	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	Centralized	✓	NS-2	✓	✓	✗
AntBeeHocNet: [36]	✗	✓	✗	✗	✓	✓	✗	✗	✓	✗	Centralized	✓	NS-2	✓	✓	✗
GeoUAVs: our solution	✗	✓	✗	✗	✗	✗	✓	✓	✓	✓	Distributed	✓	NS-3	✓	✓	✓

CHAPTER 4

CONCEPTION, PERFORMANCE EVALUATION AND NUMERICAL RESULTS OF OUR APPROACH: GEOUAVS

Contents

4.1 Introduction

In this chapter, we propose a new geocast routing protocol in fleet of UAVs namely Geocast routing protocol for fleet of UAVs (GeoUAVs) aiming at satisfying military application. It takes into account the mobility of nodes, dynamically changing topology with 3-D movement and reliability. Compared to AntHocNet [34] and BeeAdHoc [35], our proposal is able to reduce the the end-to-end delay and maximize the reliability. It also utilizes better the network throughput by avoiding unnecessary and information exchanges between UAVs.

The rest of this chapter is organized as follows: We present our new geocast routing protocol in Section 4.2. Then, the performance of the proposed algorithm are evaluated in Section 4.3. Finally, the chapter is concluded in Section 4.5.

4.2 Geocast routing protocol for fleet of UAVs

In this section, we first describe the geocast routing problem, and then present the details of our proposed approach.

4.2.1 System model

We propose a new protocol which can be applied in military context for a better performance especially in battle fields, which aims at delivering data to a specific group of mobile UAVs identified by their geographical location. Each UAV determines its own position (X, Y, and Z. where Z is a fixed point) with the help of GPS system (or any other type of positioning facility). The shape of Transmission Zone (TZ) is a square, we must ensure the delivery of information to all UAVs in the transmission zone along with the application. Initially, the source UAV (UAV_s) sends the first geocast packet P_g. The format for P_g is shown in Table 4.1.

Table 4.1: Format of geocast packet P_g

UAV_s	$TZ_s(t)$	m

UAV_s : identity of source UAV;

$TZ_s(t)$: Transmission Zone coordinate for source UAV_s at time t;

m: content of geocast message;

We denote the left axis as A_L, the right axis as A_R, the above axis as A_A and the below axis as A_B for the transmission zone $TZ(t)$. The zone creation process ensures the delivery of a geocast packet to a virtual UAV located at either A_L, A_R, A_A and A_B. as shown in Fig. 4.1.

4.2.2 Packet dissemination in TZ

When a UAV_j receives a packet P_g from UAV_i, UAV_j will verify the relevance of P_g. A packet P_g is considered 'relevant' if and only if two conditions are satisfied:

$$\begin{cases} UAV_j \text{ in } TZ(t) \\ UAV_j \text{ receives } P_g \text{ for the first time} \end{cases}$$

If P_g is not relevant, it will be rejected, otherwise, UAV_j should not retransmit it immediately but has to wait a time T_w to take a decision about the retransmission of P_g. UAV_j first calculates the closest axis A_x ($x \in \{L, R, A, B\}$) for the oriented broadcast packet in order to reduce overload. Before retransmission, UAV_j must check whether there is a UAV closer to A_x in its Transmission Range (TR). When the wait time T_w has passed and if P_g is still relevant (received only once), UAV_j deduces that there is no relay UAV closer to A_x. Then, UAV_j has to designate itself as a relay and retransmit the packet to the other UAVs closer to A_x. This verification avoids redundant multiple retransmissions, and thus permits to reduce the number of sent packets. We note $D(UAV, A_x)$ as the distance between UAV and A_x. The wait time of UAV_j receiving a packet P_g from node UAV_i is proportional to $\frac{D(UAV_j, A_x)}{D(UAV_i, A_x)}$. This is to favorite the UAV closest to A_x to wait less time and to retransmit faster. In our protocol, we use the same strategy of packet orientation in Robust Geocast Routing Protocol for Safety Applications (RGRP-SA) protocol [37].

The packet dissemination is repeated until it reaches a UAV_z which is situated in the transmission zone $\mid D(UAV_z, A_x) < TR$.

The formal description of this dissemination process is presented in Algorithm 1.

Algorithm 1: Packet dissemination in UAVs group

```
while $UAV_j$ receives packet $P_g$ from $UAV_i$ do
    if ($P_g$ is not relevant) then
        $P_g$ is deleted
    else
        if $D(UAV_j, A_R) < D(UAV_i, A_R)$ then
            $A_{x1} = A_R$
            $D_1 = D(UAV_j, A_R)$
        else
            $A_{x1} = A_L$
            $D_1 = D(UAV_j, A_L)$
        if $D(UAV_j, A_A) < D(UAV_i, A_B)$ then
            $A_{x2} = A_A$
            $D_2 = D(UAV_j, A_A)$
        else
            $A_{x2} = A_B$
            $D_2 = D(UAV_j, A_B)$
        if $D_1 < D_2$ then
            $A_x = A_{x1}$
        else
            $A_x = A_{x2}$
        // this test for oriented message to closest axis for solve overload
        $UAV_j$ calculates a random wait time $T_w$ such that
            $$T_w = \frac{D(UAV_j, A_x)}{D(UAV_i, A_x)} * T_r$$
        // $T_r$: random time uniformly chosen in $[0,1]$
        When the timer expires;
        if ($P_g$ is not relevant) then
            $P_g$ is deleted
        else
            if ($\exists UAV_k$, such that $(D(UAV_k, A_x) < D(UAV_j, A_x))$ and ($UAV_k$ in $TZ(t)$)) then
                $UAV_j$ broadcasts packet $P_g(UAV_j, TZ_{UAV_j}(t)$, m) // avoid periodic exchange of packets
```

4.2.3 Example of GeoUAVs Method

Fig. 4.1 gives an example to illustrate the dissemination of geocast packet to all UAVs in a transmission zone through the relays closest to the left axis A_L, the right axis A_R, the above axis A_A and the below axis A_B. Let UAV_s be the source drone.

Drones $UAV_A \sim UAV_I$ are located in $TZ(t)$, and must receive the packet from the source drone UAV_s. In the beginning, UAV_s broadcasts the geocast packet to UAV_A, UAV_B, UAV_C within its transmission range. Drones UAV_A, UAV_B, and UAV_C are respectively the closest to A_R, A_A and A_L, so they retransmit the packet to $V_D \sim V_I$. For instance, UAV_A calculates the distances $D(A, A_R)$ and $D(S, A_R)$, $D(A, A_R)$ is inferior to $D(S, A_R)$, thus $A_{x1} = A_R$ and $D_1 = D(A, A_R)$. Then, UAV_A calculates the distance $D(A, A_B)$ and $D(S, A_B)$, $D(A, A_B)$ is inferior to $D(S, A_B)$, thus $A_{x2} = A_B$ and $D_2 = D(A, A_B)$. After that, it chooses the closest axis with the minimum of distance between D_2 and D_1 (in our example, $D_1 < D_2$), so $A_x = A_R$. In other words, the chosen axis is the closest one to the receiver UAV_A then the sender UAV_s. Than, UAV_A calculates a wait time T_w (cf,. Algo 1), when a timer expires, if it not receive the same information sent from any other drone (The relevance of the information) it verifies the presence of another drone closest to A_x. In the case of our example, UAV_A finds UAV_F, so it broadcasts the information. UAV_F performs the same calculations as UAV_A and retransmits the packet to UAV_E. Also, UAV_E performs the same previous calculations and not find other drone closest to the one of the axis which lead it to stop the broadcasting. All the receivers of the message preform the same calculations. The procedure is continued until all drones in current $TZ(t)$ are informed.

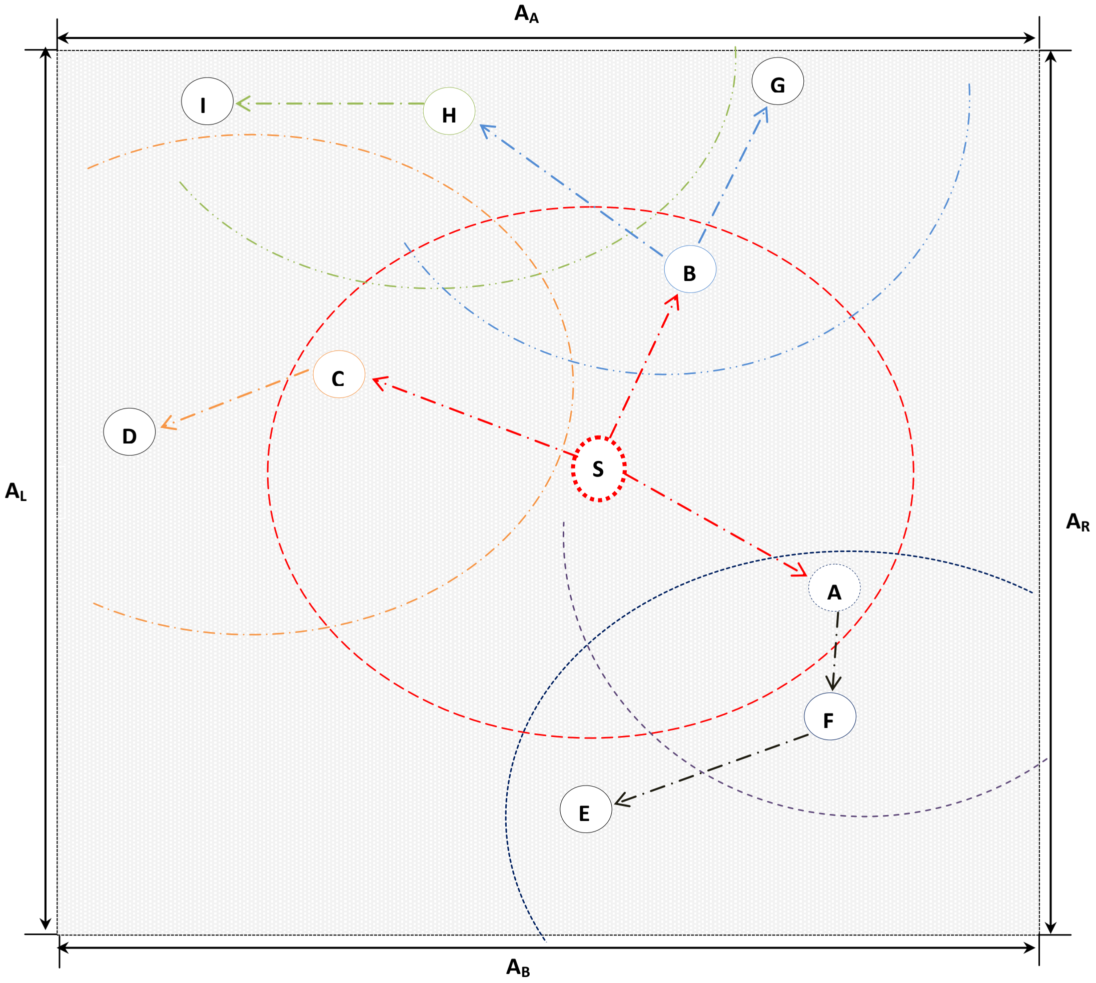


Figure 4.1: Packet dissemination in GeoUAVs.

4.3 Performance evaluation and numerical results

We use NS-3 [38] tool to evaluate the performance of our proposed protocol GeoUAVs. The programming languages in NS-3 are C++ and Python. The NS-3 project, started in 2006, is an open-source project developing NS-3. This simulator is composed of huge technological networks and protocols. It helps the users to create their own models. NS-3 is chosen for its effectiveness.

We compare our algorithm with the state-of-the-art AntHocNet [34] and BeeAdHoc [35] to show theirs advantages through two different scenarios. '

Table 4.2: Simulation configurations

Parameter	Value [GeoUAVs, AntHocNet, BeeAdHoc]: 1^{st} scenario	Value [GeoUAVs]: 2^{nd} scenario
Mobility Model	Random waypoint	Random waypoint
Number of UAVs	10-50	10-100
Velocity	20-50 m/s	20-50 m/s
Simulated area	1500 m x 1500 m	10000 m x 10000 m
Simulation runs	10	10
Transmission range	250 m	1000 m
Simulation time	20 seconds	100 seconds
MAC layer protocol	802.11	802.11
Packet size	512 Kbytes	512 Kbytes

1. In the first scenario, we use the same modeling parameters as AntHocNet [34] and BeeAdHoc [35]: we use an area of 1500 m x 1500 m as the simulation environment. Random waypoint mobility model is utilized. The speed of UAVs varies from $20m/s$ to $50m/s$. The MAC layer protocol used in this simulation is the 802.11 protocol. We study the network performances while increasing gradually UAV density. The number of UAVs ranges from 10 to 50. Simulation time is 100 seconds, while the transmission range of UAVs is set to 250 m. The obtained results are the average of 10 simulations.

2. In the second scenario, we evaluate our proposal in an area of 10000 m x 10000 m as the simulation environment. The number of UAVs ranges from 10 to 100. Simulation time is 100 seconds, while the transmission range of UAVs is set to 1000 m. Simulation parameters are summarized in Table 4.2.

We are interested in the following performance metrics:

1. **End-to-End Delay (EED)**. It is the average time (in seconds) needed for a packet to reach its destination.

2. **Throughput Utilization (TH)**. It is the total number of packets successfully transmitted in $TZ(t)$ divided by the simulation time.

3. **Packets Delivery Ratio (PDR)**. It is the number of packets successfully received divided by the number of packets generated.

4.4 Simulation Analysis

4.4.1 Simulation analysis

We first compare the performance of the proposed GeoUAVs with the AntHocNet and BeeAdHoc algorithms. Simulation results are shown in Figs. 4.2 and 4.3.

In the first scenario, we use the same parameters used in AntHocNet and BeeAdHoc algorithms [29].

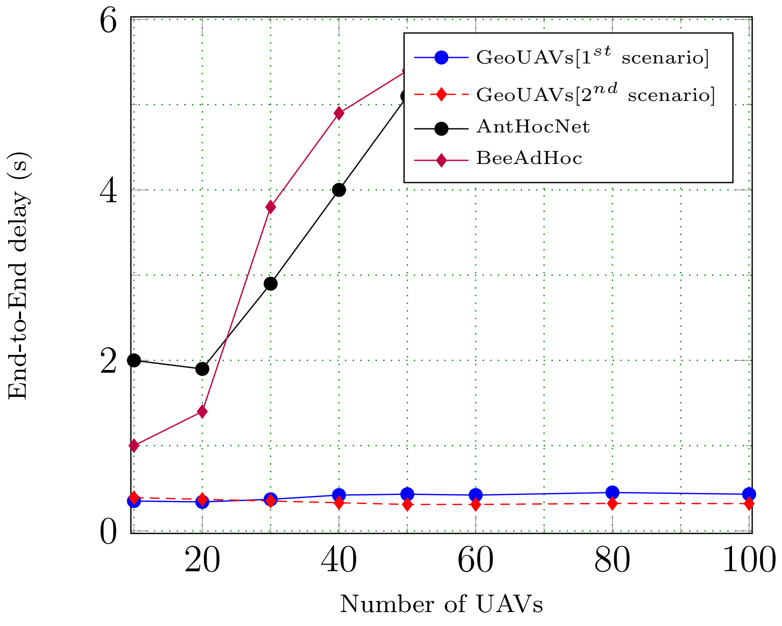


Figure 4.2: End-to-End delay vs. UAVs density

Fig. 4.2 illustrates the performance of end-to-end delay. It is noted that GeoUAVs is able to reduce the end-to-end delay compared with AntHocNet and BeeAdHoc, and the delay increases whenever the network density increases in both AntHocNet and BeeAdHoc protocols, whereas in both two scenarios of GeoUAVs the delay is not increased significantly (0.31s ∼ 0.45s). There are two reasons for this. First, it is due to the correct orientation of the packet transmission (Algorithm 1: lines 5 ∼ 20). Second, the waiting time for a UAV to rebroadcast a packet is well determined (Algorithm 1: line 22). This helps reducing the number of relays in the packet delivery. Consequently, the end-to-end delay decreases. This confirms the feasibility of GeoUAVs protocol.

The utilization of throughput is presented in Fig. 4.3. For all algorithms (GeoUAVs, AntHocNet and BeeAdHoc), the network utilize more throughput as the total number of UAVs grows. But, we can clearly find that our approach GeoUAVs achieves almost half plus the throughput utilization of AntHocNet and BeeAdHoc. Because GeoUAVs needs less time (Fig. 4.2) to route packets to all UAVs in $TZ(t)$. This helps to maximize the throughput. Thus, this metric also confirms the advantage of our GeoUAVs protocol.

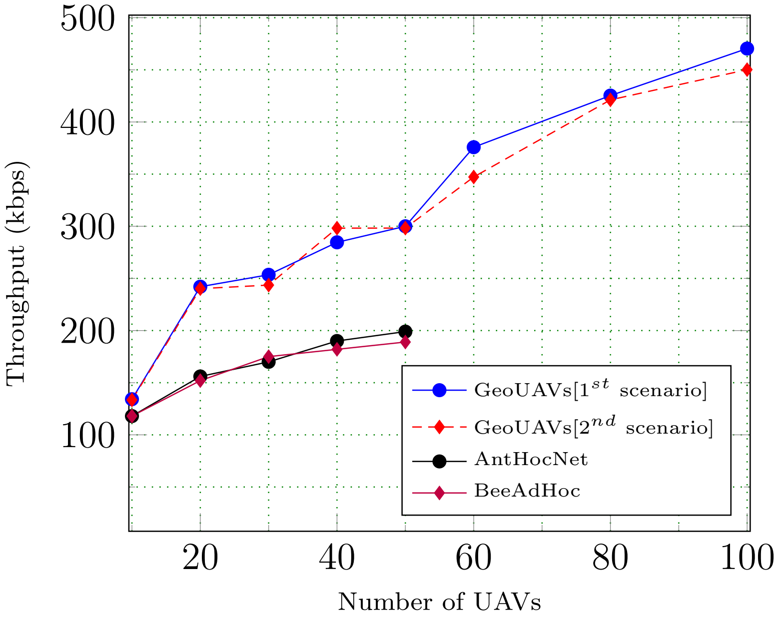


Figure 4.3: Throughput vs. UAVs density

We also compare Packets Delivery Ratio of our protocol in Fig. 4.4. The curves show that GeoUAVs has a packet delivery rate up to 76% for all network densities. Thus, our solution provides the best results. In both two scenarios, GeoUAVs uses the same strategy to disseminate the packets (Fig. 4.4). So we can say that GeoUAVs overcomes the frequent disconnection in the network topology, what enables to increase the packet delivery ratio for all network densities. The rise of PDR amount can be explained with the lack of packet lost and vice versa. The loss is due to many factors among them the collision and overload.

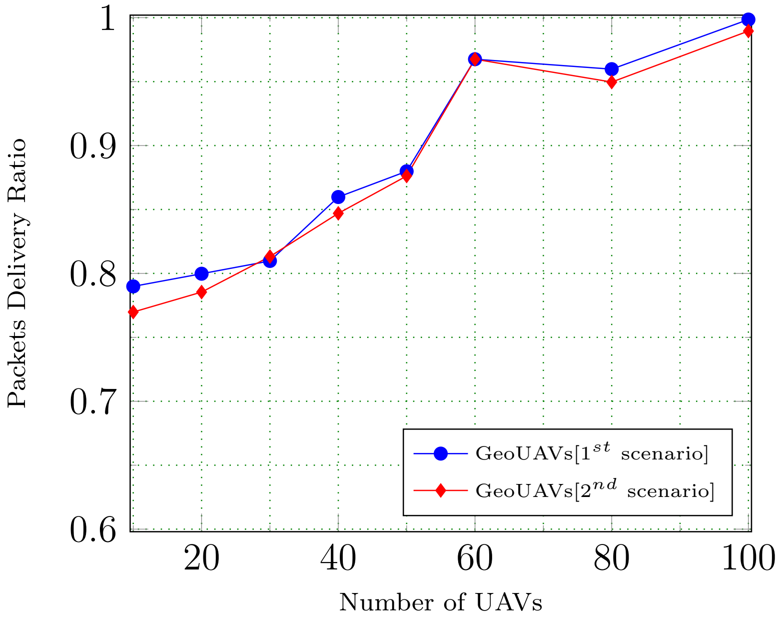


Figure 4.4: Packets delivery ratio vs. UAVs density

4.5 Conclusion

In this chapter, we presented our geocast routing protocol for fleet of UAVs. The proposed protocol GeoUAVs is designed for delivering delay-critical short packets while taking into account the mobility of UAVs. Simulation results demonstrated that GeoUAVs protocol outperforms AntHocNet and BeeAdHoc by reducing the end-to-end delay. Also, simulation results evidence that GeoUAVs protocol is able to provide more reliable data delivery and higher throughput use compared with AntHocNet and BeeAdHoc protocols.

Simulation results revealed that GeoUAVs protocol is better performing and more effective than AntHocNet and BeeAdHoc protocols.

CONCLUSION AND SUGGESTED FUTURE PERSPECTIVES

-Summary of our work

In this work we have proposed a new geocast routing protocol, designed for fleet of UAVs in FANET. At first in the theoretical part, we have discussed the general concepts of the fleet communication in FANET. Therefore, we have presented the state-of-the art of UAV's fleet and we have illustrated the different fleet routing protocols in FANET with a detailed comparison of all discussed protocols.

Second, we have presented the detailed of our new geocast routing protocol for fleet of UAVs in FANET.

In the last step of our work, we have implemented our proposal using different languages and simulator. The results of the simulation conducted using NS-3 simulator demonstrate the effectiveness of our protocol proposed in this work in terms of reducing the average delay, increasing both the throughput and packet delivery ratio. The simulation validation confirms also the performance advantage of our solution compared to the up to date protocols in the literature that tackle the same problems.

-Faced problems

Our work was not an easy job to be conducted. We faced some problems in realization building of this research. One of the main obstacles that impacts in our way is the lack of resources, specially those related to the simulator. This might be due to the poor use of this simulator in this field.

-Benefits and future perspectives

The main purpose of this work was to practice our skills and learn some new languages and simulator, we think it was really helpful. Although this work still has so some points that need to be improved. We intend to tackle some future perspectives should be considered to design a new version:

- First, future work will be mainly focused on the performance analysis of our new protocol in real scenarios using mobility traces taken from real experiments.
- In addition, we plan to use another simulators.
- Finally, we plan to extend GeoUAVs by considering others parameters and new methods to achieve more reliability and scalability.

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