NATURAL DISASTER MANAGEMENT WITH MULTI UAV SYSTEMS

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Master's Thesis

Department of Electrical and Electronics Engineering

Programme in Telecommunication

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Eskişehir

Eskişehir Technical University

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ABSTRACT

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The occurrence of natural disasters is getting increase in recent years compared with the past, and these disasters cause millions of casualties every year. It is critical for humanity to minimize losses caused by disasters, which seriously affect social and economic balance, as well as casualties. There is a lot of studies in the literature regarding the management competencies of Unmanned Aerial Vehicles (UAVs) in emergencies such as natural disasters.

In the context of natural disaster management, this study defines the role of UAVs and presents disaster management with swarm of UAVs using existing methods and technologies in an exemplary earthquake scenario simulated in Gazebo environment. Here, UAVs not only search the disaster area, but also deliver the injured victims to the nearest hospitals and provide telecommunication services for healthy survivors.

The aim of this study is to create a complete disaster management system by providing useful technical results to improve the welfare of people in emergencies such as natural disasters. In this context, the stages that need to be followed before and after the disaster are examined, alternative network architectures that can be used by UAVs are presented and all wireless communication technologies that can be provided for different needs are examined and compared.

Keywords: Unmanned Aerial Vehicles, Natural Disaster Management, Gazebo, Swarm of UAVs, Wireless Networks, Networking Architecture, Earthquake, Forest Fire.

ÖZET

SÜRÜ İHA'LARLA DOĞAL AFET YÖNETİMİ

Merve MUSLU

Elektrik ve Elektronik Mühendisliği Anabilim Dalı

Telekomünikasyon Bilim Dalı

Eskişehir Teknik Üniversitesi, Lisansüstü Eğitim Enstitüsü, Ağustos 2020

Danışman: Doç. Dr. Tansu FİLİK

Son yıllarda geçmişe kıyasla daha sık görülen doğal afetler, her yıl milyonlarca can kaybına sebep olmaktadır. Can kayıplarının yanında, sosyal ve ekonomik dengeyi de ciddi ölçüde etkileyen bu afetlerden kaynaklı kayıpları minimuma indirgemek insanlık için kritik bir önem arz etmektedir. İnsansız Hava Araçlarının (İHA), doğal afetler gibi acil durumlardaki yönetim yetkinlikleri ile ilgili literatürde birçok çalışma bulunmaktadır.

Bu çalışmada ise, doğal afet yönetimi bağlamında, İHA'ların rolünü tanımlayarak, Gazebo ortamında simüle edilmiş örnek bir deprem senaryosunda, sürü İHA'ların mevcut yöntem ve teknolojilerle afet yönetimi sunulmuştur. Burada, İHA'lar sadece afet bölgesini aramakla kalmaz, aynı zamanda yaralı kazazedeleri en yakın hastanelere ulaştırır ve sağlıklı olan kazazedeler için ise telekomünikasyon hizmeti sağlarlar.

Bu çalışmanın amacı, doğal afetler gibi acil durumlarda insanların refahını iyileştirmek adına, yararlı teknik sonuçlar sunarak tam bir afet yönetim sistemi yaratmaktır. Bu bağlamda, afet öncesi ve afet sonrası takip edilmesi gereken aşamalar incelenmiş, İHA'ların kullanabileceği alternatif ağ mimarileri sunulmuş ve farklı ihtiyaçlar için sağlanabilecek tüm kablosuz haberleşme teknolojileri incelenmiş ve kıyas edilmiştir.

Anahtar Sözcükler: İnsansız Hava Araçları, Doğal Afet Yönetimi, Gazebo, Sürü İHA, Kablosuz Ağlar, Ağ Mimarisi, Deprem, Orman Yangını.

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17/08/2020

STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific ethical principles and rules throughout the stages of preparation, data collection, analysis and presentation of my work; that I have cited the sources of all the data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this study has been scanned for plagiarism with "scientific plagiarism detection program" used by Eskişehir Technical University, and that "it does not have any plagiarism" whatsoever. I also declare that, if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that are involved.

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1. INTRODUCTION

The percentage of happening of natural disaster scenarios has increased noticeably in the last decades. This is a significant distress because it causes to the destruction of infrastructure, social and economic instability, and loss of life. Expression of disaster is defined as being exposed to or interacting with any hazardous events that caused serious disruption of the functioning of a society or a community that caused humanistic, materialistic, and economic losses and effects according to United Nations International Strategy for Disaster Reduction (UNISDR) [1].

Most of the natural disasters have a serious economic impact, albeit in short-period, but in some conditions, that may cause to long-period economic losses [2]. The main cause for the rising effect of the disasters is the rapidly increasing population expansion and the skewed urbanization, especially in coastal, urban or the greenbelt areas. Global warming and other factors like population expansion, environmental breakdown, and deforestation are also the cause of such disasters [3].

According the world disaster report of 2018 [4], 3751 natural hazards occurred with an approximate loss of 2 billion human lives over the last ten years. Long-period negative effects - beyond the direct damages of infrastructure and life - in the form of public crises, health issues and ecological problems are spied for the next terms [5]. Most of the developing countries, big metropolitan cities with the increasing population, are strongly sensitive with the concerned officials to disaster fields since there is a critical lack of situational information and sources [6].

These reported natural disasters can also take place in different and wide areas. The use of autonomous (unmanned) vehicles, which have become widespread in recent years, against these disasters in large areas, has been brought to the agenda in collaboration. Considering the features of UAVs', UAV networks is the best option to have the integrated system which can manage the disasters in large areas. The reason is that the fastest and most efficient situational awareness is reached by the means of aerial assessment – with multiple UAV networks [7].

1.1. Problem Statement

Damages and casualties caused by natural disasters are of great importance, and most of these damages and losses are occurred due to the lack of early warning system. Therefore, an appropriate monitoring and detection system is needed to give people an early warning message before a disaster occurs or causes greater damage. In the literature, lots of descriptions are done for an early monitoring system. The system is defined in [76], as “monitoring device,

which is designed to avoid, or to reduce the impact on humans, the damage on property and environment." Also, [9] describes the system as "the set of capacities required to generate and propagate timely and meaningful warning information to allow individuals, and communities who are threatened by a hazard to make provision for and to behave appropriately in sufficient time to minimize the possibility of harm or loss."

The systems for telecommunications are also another critical necessity in decreasing the impact of natural disaster by supplying the required connectivity, but most of the systems are not serviceable when needed the most, directly after the natural disaster. Therefore, there is also a need for a mobile and autonomous system to provide telecommunication [10].

By using UAV networks, first responders can get the information about the number of structures affected by the disaster, the extent and damage to the constructions, the situation of transportation infrastructure and the estimated number of people who are affected by the disaster. However, the networks still cannot efficiently handle with the problems such as processing power limitations, power supply limitations, unexpected node failures, unreliable communication channel, maneuverability in harsh conditions, and maximal physical load size [7]. These problems cannot be underestimated in driving the time critical SAR missions.

1.2. General Overview of the Thesis

In this thesis, the various approaches are investigated for natural disaster management and a simulation environment is prepared. These approaches are tested on the simulation environment to get the optimum results. These results are expected to serve like an information platform towards the plan of an optimized, and comprehensive solution to help humanity in case of natural disaster scenario.

We used the Gazebo environment [8] to simulate the multiple UAVs in natural disaster scenario for, detection, mitigation and management problems with optimized techniques. The Gazebo environment is widely used for multi robot and UAV simulations [9].

The natural disaster management system is separated into different subsystems and subproblems are defined as follows:

1. Formation flight system: Formation flight is the coordinated flight of UAVs for achieving a specific mission. There is a need for system which has a formation controller to achieve this flight. There are many studies in the literature that search and study the theory behind performing a successful and powerful formation flight controller for different types of UAVs [83].

2. System of creating navigation route points: UAVs will share the disaster areas to be searched and rescued, considering their capabilities and aerodynamic structures. Navigation route points are created in the shared areas, according to their capabilities and aerodynamic structures and the UAVs will take their action to search by going to these route points.
3. Fully autonomous UAV navigation system: The flight controller and navigation system should be robust to make autonomous navigation for UAVs from point to point. The system directs the UAVs to the 3-dimensional (3D) coordinate point, which will provide the latitude, longitude and altitude values entered. The system will consist of two subsystems, as low and high resolution. The low-resolution navigation system will bring UAVs from one point to another point with a certain distance error. High-resolution, short-range system will be used to go to a point where the 3D position is given and hang in the air (take-off, landing, evacuation procedures, etc.) Therefore, it is required to have a high-resolution navigation controller that can accommodate various linear and nonlinear control theories.
4. Personnel tracking and evacuation system: UAVs will check the data provided by the camera on them for the entire time they navigate. In case of detection of the casualty entering the field of view, the UAV will interrupt the search journey and the UAV will approach the position of the victim and descend to the evacuation altitude and take the victim to UAV. Afterwards, the closest and most appropriate hospital will be determined, and the personnel will be evacuated to this position. After evacuation, the UAV will head to the search navigation route point where it left off.
5. Telecommunication system: This system should provide wireless communication service for healthy people in the disaster area. UAVs should be in the specific altitude to ensure this service. UAVs act as base stations in defined areas, and they make it happen.
6. Obstacle avoidance system: This system should provide the UAVs to stay away from the no-fly zones, tall buildings (obstacles), and other UAVs in the herd. The system that will be developed in UAVs will be created as the implementation of the algorithm and the algorithm will be fed with static and dynamic obstacles and provides the UAVs will be avoided from the obstacles.

In this thesis we developed some algorithms and strategies for the defined natural disaster scenario considering the literature with real constraints. All these systems and algorithms are driven (implemented) in the Gazebo simulation environment to show the results.

1.3. Overview the Thesis Chapters

The outline of the thesis is given below:

- In Chapter 2, a general definition and classification of UAVs are done, and the history of UAVs are mentioned. The advantages of using UAVs as swarms and the usage areas of UAVs are given.
- In Chapter 3, critical stages for natural disaster management are presented and the characteristics of the UAVs planned to be used in this management are mentioned. Suggested UAVs that can be used in a sample earthquake scenario are introduced.
- In Chapter 4, networking architectures that can be used in swarm of UAV systems are presented and discussed.
- In Chapter 5, due to the collapse of the communication structure in a hypothetical natural disaster scenario is given and, the existing wireless communication technologies that can be used to temporarily reconfigure the communication system with multiple UAVs have been introduced and compared.
- In Chapter 6, a possible earthquake scenario is simulated in the Gazebo environment. In the environment, disaster management is carried out with swarm of UAVs. Images from the simulation environment and the output of the code scripts in the Python environment are presented in this section.

1.4. Contributions

There are many research and studies about the usage of multiple UAVs in literature. In this thesis, the role of UAVs in natural disaster management is investigated and the scenario of disaster management is presented. Alongside the literature research, simulation of disaster management with swarm of UAVs is studied. The combination of disaster management and engineering requirements are introduced. Design solutions' algorithms and strategies which are suitable for each defined system are explained.

2. MULTIPLE AUTONOMOUS UAV SYSTEMS

2.1. Definition, Classification and History of UAVs

Definition of UAVs

The name of Unmanned Aerial Vehicles (UAVs) cover all the vehicles which can fly in the sky, unmanned and having a capability of controlling the aircraft. UAVs accomplish their mission by ground remote control or by pre-input programs[12].

In addition to that, although the term of UAV is admitted definition in all professional and non-professional area, some associations such as International Civil Aviation Organization (ICAO) stress the clear distinctions in UAVs. According to ICAO, there are three types of UAV such as, Remotely Piloted Aircrafts (RPAs), the autonomous aircrafts and the model aircrafts. The autonomous aircrafts are generally used in the military services. They do not let pilot interventions during the flight. The former one which is remotely piloted aircrafts refers to unmanned aircrafts. These aircrafts are generally utilized for civil applications. As a last, the third ones are the model aircrafts which are generally used for fun. There are lots of model aircraft school in most of the country to encourage and inform people [14].

Any flying object by using remote control or automatically with non-person on board can be defined as an aircraft. The statement of Unmanned Aircraft System (UAS) was accepted by the United States Department of Defense (DoD) and the United States Federal Aviation Administration (FAA). The UAS is defined as the unmanned aircraft with all the equipment to operate the vehicle such as control station, telemetry, navigation, data links and communications equipment according to FAA. Instead of UAV, Unmanned Vehicle Systems (UVS), Remotely Piloted Vehicle (RPV), model helicopter, Remote Controlled Helicopter (RC-Helicopter) and Remotely Operated Aircraft (ROA) kind of terms also used [12].

Classification of UAVs

UAVs are classified in terms of several parameters. Universal classification parameter which is commonly used is mass. UAVs are designed and produced in various sizes which start from very small dimensions according to the job description. Therefore, their mass varies in direct proportion to their size. According to the Turkey's Civil Aviation General Directorate (SHGM), the UAVs are classified under 4 classes according to their maximum take-off mass. The classification of SHGM for UAVs is shown in Table 2.1 [16].

Table 2.1. *The SHGM Classification of UAVs*

Class	Mass
UAV0	Between 500 gr and 4 kg
UAV1	Between 4 and 25 kg
UAV2	Between 25 and 150 kg
UAV3	More than 150 kg

On the other hand, in the military field, the Joint Air Power Competence Centre (JAPCC) classification is also approved by NATO. The main factor in this classification is the mass and, the task height and duty radius of the UAVs do not cause transitions between classes. Table2.2 provides the details of the classification, including the task height and task radius [12].

Table 2.2. *The JAPCC Classification of UAVs*

CLASS	CATEGORY	NORMAL EMPLOYMENT	NORMAL OPERATING ALTITUDE	NORMAL MISSION RADIUS
Class I (Less than 150 kg)	SMALL More than 20 kg	Tactical Unit (employs launch system)	Up to 5K ft AGL	50 km (LOS)
	MINI Between 2-20 kg	Tactical Sub-unit (manual launch)	Up to 3K ft AGL	25 km (LOS)
	MICRO Less than 20 kg	Tactical PI, Sect, Individual (single operator)	Up to 200 ft AGL	5 km (LOS)
Class II (Between 150 and 600 kg)	TACTICAL	Tactical Formation	Up to 10,000 ft AGL	200 km (LOS)
Class III (More than 600 kg)	Strike/ Combat	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)
	HALE	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)
	MALE	Operational/Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)

The last classification, which is done according to their aerodynamic flight principle illustrated in Table 2.3.

Table 2.3. *The Aerodynamic Classification of UAVs*

UAV TYPE	ADVANTAGE	DISADVANTAGE	APPLICATION AREAS
Fixed-wing	Large area coverage, Long flight time	Inconvenient launch and landing	Surveying an area, Structural investigation
Rotary-wing	Hover flight, Increased payload,Vertical take-off and landing	Short flight duration, Short range	Aerial investigation, Supply delivery, Aerial inspection, Filmography, Photography

History of UAVs

UAVs have been around for centuries and they were only utilized for military purposes. However, the oldest recorded usage of a UAV is 1849 when the Austrians assaulted the Italian city of Venice with unmanned balloons which were filled up explosives. Even though balloons would not be considered as a UAV today, that was a technology which the Austrians had been improving for months before and led to farther advancements. In 1915, in the Battle of Neuve Chapelle, British military took advantage of aerial photography. They were capable to capture much more than 1,500 sky view maps of Germany.

During the First World War in 1916, the US began evolving UAV technology and they produced the first pilotless aircraft. Soon after, the army of US built the Kettering Bug. In 1930, the Navy of US started experimenting by radio-controlled aircraft and as a result, they created the Curtiss N2C-2 drone. During the World War II, first remote-controlled aircraft named the Radio plane OQ-2 is created by Reginald Denny. That creation was the first UAV product which is massed produced in US. It was a breakthrough for the military to produce and supply UAVs.

There was an assumption about UAVs for being expensive and unreliable toy, however this attitude started to change in the 1980's. In 1982, the victory of Israeli Air Force to the Syrian Air Force contributed to this changing. Israel used unmanned and manned aircraft to break down a dozen of Syrian aircraft within minimum losses. Furthermore, the US composed the Pioneer Program of UAV to execute the need for unmanned and cheap aircraft for navy operations in 1980's. A new UAV was built from a collective project between the US and Israel in 1986. The UAV was accepted as RQ2 Pioneer which was a reconnaissance aircraft in a medium size.

In 1990, micro and miniature UAVs were presented. In 2000, the US instructed the Predator drone in Afghanistan during the searching for Osama Bin Laden. Even though, most remarkable UAV flights have been done for military goals, technology is keep going to improve and get more attention [19].

In the near past, in 2014, while most of the UAV flights were for military goals, Amazon offered the usage of UAVs for delivering goods. UAVs also went to popular for photography and filming. After that, the interest in UAVs have started to increase not due to military influence. It is the result of merging of radio-controlled (RC) aircrafts and smartphones.

The fast growth in the use of smart phones decreased the prices of camera sensors, accelerometers and microcontrollers which is used for fixed-wing hobbyist aircraft. There is also a rapidly growing trend which is DIY small RC UAVs. These UAVs have been using by police forces and fire services for surveillance requirements thanks to their portability and smaller size.

Today's world has been trying to improve more peaceful and civil usage of UAVs compared with the past. Commercial UAVs' market has been enlarging super quickly and that is why tracking the developments of UAVs also have been become so hard. During the last decade, the UAV technology is becoming integrated into entire kinds of industries. For instance, such as package delivery, law enforcement, military operations, agriculture crop surveying, recording concerts, film making, humanitarian aid efforts and SAR are some well-known usages of UAVs technology [21].

On the other hand, the future of UAVs seems extremely promising. UAVs are expected to turn out lighter and smaller with long flight times, fuel, or battery in military applications. There will be also some developments to improve the optics and other capabilities farther. Additionally, there will be developments in the civilian market such as improving times of flight to serve as emergency service, surrender platforms and as an information collector for forestry and agriculture. Development in the aspect of machine vision, onboard processing power and flight control algorithms will farther enable these UAVs to get verdicts themselves instead of relying on human beings with less maneuvering expertise [20].

2.2. Advantages of Multi UAVs

Manufacturing of mini or small UAVs (class-1, Table 2.2) has been possible at a low cost thanks to the development of embedded systems and the miniaturization propensity of microelectromechanical systems. However, a single small UAV has a limited capability (range

and battery) [24]. Choosing a small scaled UAVs instead of to choose a large one is more practical for commercial applications because of their simplicity of deployment, low maintenance and acquisition costs, elevated maneuverability, and capability to hover. These small UAVs are being used in monitoring of ecological and natural disasters, surveillance of borders, emergency support, the missions for SAR and delivery of goods [25]. Collaboration and coordination of multiple UAVs can build a more efficient system rather than the capacity of only one UAV. Multi UAV systems has advantages as followed.

Cost- The cost for maintenance and acquisition of small UAVs is lower rather than a large UAV [27].

Scalability- A large UAV can cover only a limited amount of area. However, scalability of the operation can be extended easily by multi UAV systems [28].

Survivability- If the UAV fails in the duty which is managed by one UAV, the mission cannot keep going. However, if multi UAV system is used instead of single UAV, the mission can keep going with other UAVs.

Speed up- It is claimed that the duties can be completed quicker with multi UAV systems rather than the single UAV [29].

Small radar cross section- Multi UAV systems can produce very small radar cross sections which is important for military operations instead of one large radar cross section [30].

Additionally, the comparison of single and multi UAV system is shown in Table 2.4.

Table 2.4. *Comparison of Single UAV System and Multi UAV System*

Features	Single UAV System	Multi UAV System
Survivability	Poor	High
Scalability	Limited	High
Speed of Mission	Slow	Fast
Unit Cost	Medium	Low
Radar Cross Section	Large	Small
Required Bandwidth	Medium	High
Antenna	Directional	Omni-Directional
Complexity of Control	Low	High

Even though there are lot of advantages of using multi UAV systems, it has some specific difficulties, such as communication in compared with the single UAV systems. A satellite or ground base is utilized for communication in a single UAV system. Establishing a

communication connection between the airborne control system and the UAV is also possible for single UAV systems. In all conditions, the communication for single UAV systems is set between the infrastructure and the UAV. While the number of UAVs rises, the network architectures become more complex. That is why, designing efficient network architecture becomes an essential issue for multi UAV systems [24].

The usage of multi UAV systems as aerial base stations or communications relays for providing network in emergency situations has been of especially interest because of their wide coverage capabilities and fast deployment. For different utilizations, the number of and the travel distances of UAVs vary via a wide range. This variation can be seen in Figure 2.1 as an illustration [32].

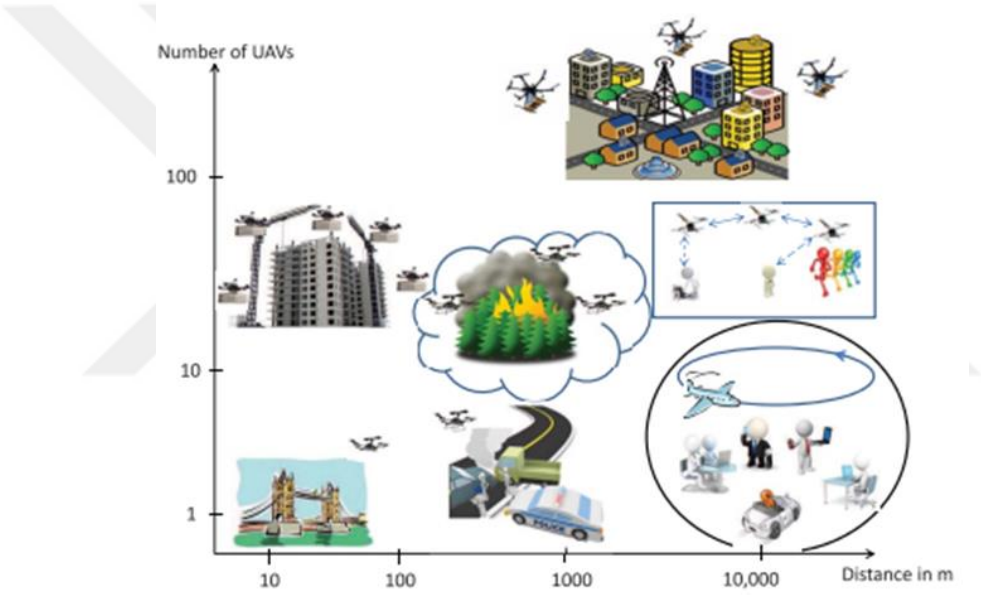

Figure 2.1. *Application areas for different number of UAVs and different range of distances*

Multiple UAV systems can be deployed as aerial base stations to ensure service for affected areas in disasters or as an aerial sensor network for gathering data in wide areas. These multi UAVs can have a powerful potential to apply missions which go beyond the individualistic talents of the small UAVs. Networking and communication are necessary to obtain autonomous aerial networks and coordinate multiple UAVs. For several implementations with certain QoS (Quality of Service) demands, connectivity and qualified wireless links in 3D space is required. For this reason, determining which tech of wireless should be utilized for aerial networks will be necessary. The tech of choice should support the

air to air links and air to ground links, paying attention to the data supposed to be delivered, in any case of important orientation and height differences [34].

2.3. The Usage Areas of Multi UAVs

Nowadays, the data which are obtained by remote sensing methods, processed, and made meaningful are used in many different areas. Until recently, helicopters, airplanes, manned aerial platforms, or satellites have been used for this purpose. In recent years, UAVs have started to take the place of these platforms and the usage density is increasing day by day. The reasons for preferring UAVs are listed.

- The costs of design, production, operation, and maintenance for UAVs are much lower than other vehicles. Especially, with the tasks that need to be repeated repeatedly causes huge costs for airplanes.
- Depending on the imaging sensors on the aircraft or satellite, atmospheric conditions remain a major obstacle to imaging.
- Remote sensing satellites constantly pass through different points and it is not possible to receive images from the desired region at any time.
- The usage of UAVs is more appropriate under difficult conditions, which may endanger human health, especially in the military field.
- Longer flights that cannot be performed on manned flights can be carried out continuously with UAVs.
- Thanks to the high level of autonomy, it is possible to complete the mission and secure the landing of the UAVs even if communication with the ground station is lost.
- Depending on their size, UAVs are disposable or short-run aircraft. So, they do not need runways.

In addition to these advantages of the use of UAVs, it is considered that it is possible to use these systems in many areas when the mentioned advantages of herd UAV systems which result from the use of UAVs together. The usage fields cover a wide range of areas from agricultural practices to forest fires, from human studies to natural life to military applications. The following topics provide detailed information about these areas [17].

2.3.1. Agriculture

Agriculture is one of the areas which UAVs are used in civilian area. In the case of agriculture, different practices are carried out. It is seen that different applications such as

monitoring the maturity of seeds, monitoring the fields, monitoring the productivity of rice fields in Asia, determination of healthy and diseased areas, and application of pesticides are observed. It is also considered that similar applications can be realized with herd UAV systems in a shorter time and with lower costs. The most practical solution that can be offered is that multiple UAVs perform autonomous flight and display on the selected agricultural area in parallel with each other following the predetermined route.

2.3.2. Leak detection

Leaks are one of the most dangerous issues for human life that arise because of natural disasters or human error. These may be gas leaks or nuclear leaks that occur in nuclear facilities, potentially causing permanent damage to humans for generations. Especially, these leaks, which have extremely high risks for human health, can be detected more safely by UAVs and the protection of living spaces can be ensured. When these tasks are performed using multiple UAV systems, the detection time of the leak source is significantly reduced

2.3.3. Atmospheric data collection

Environmental awareness in our country and around the world is increasing day by day. Therefore, there has been a need to assess the levels of pollution in the atmosphere, to determine what needs to be done to control and reduce it. For this purpose, a wide variety of systems have been developed from satellite-based monitoring systems to typical local stations or public transportation in cities. Most of these systems are designed to detect pollution levels at ground level or in much larger areas, such as at satellites. For example, forest fires or pollution from factories cannot be accurately measured by ground-based systems and are often neglected. This is where monitoring systems based on UAVs can be used.

2.3.4. Forest fire

Forest fires are a disaster that has a negative impact on the environment and adversely affects both human life and the economic situation of countries. The emergence of this catastrophe is directly linked to natural factors such as forest type and weather conditions, as well as to people's behavior. Considering the possibility of rapid expansion of the affected area, forest fires are likely to have serious consequences. In our country, forest fires are widespread in the coastal regions of the Aegean and Mediterranean regions. Particularly in the summer months, there is a significant increase in the number of forest fires due to the increase in

temperature and precipitation. This situation threatens both natural and human life. To prevent forest fires, UAV systems are preferred in recent years and losses can be reduced to a great extent by measures taken early. With herd UAV systems that can be used in larger areas, much larger forest areas can be monitored and protected simultaneously

2.3.5. Natural disaster

Aerial visual data of buildings, roads and pedestrian traffic in the turmoil that emerges after disasters occur is very important information to create a new safe map. It also allows the creation of a real-time monitoring system of received data. All of these can be used to identify areas where urgent help is needed and secure areas where people can be located until conditions return to normal.

UAVs are being used as one of the first options especially in cases where the efficiency of land vehicles such as earthquakes, floods, tsunamis decreased to a great extent and the capabilities of people are limited. As a method, a single UAV's image is preferred.

However, in cases where there is more than one task to be performed in the task area or when a single task needs to be performed in a very short time, the usage of multi UAVs is important in terms of increasing functionality and developing solutions in a short time. Disaster management issues can be classified as following.

- Monitoring and early warning systems,
- Disaster information system and sharing,
- Situational awareness and logistics,
- Independent communication system,
- Search and rescue missions,
- Damage detection.

2.3.6. Alternative uses

It is possible to diversify the civil and military uses of these vehicles as well as the herd UAV uses mentioned above and tested by simulation or real applications. Some of those are listed such as:

- Screening of the region and carrying out SAR activities in airplane or helicopter accidents that occur in areas where people are difficult to access,
- Monitoring of oil, oil and fuel spills that occur after seaside accidents and which have great risks for natural life as another leg of leak detection,

- Determination of traffic densities in different regions of cities,
- Use of flocks as broadcasting platform in areas where communication facilities are limited (such as lack of infrastructure or damage).
- Monitoring of large-scale refugee movements.

In addition to all these areas of civil use, it is possible that different areas of use will emerge in the distant future. UAV swarms can be used to make different measurements in deep space researches. In this way, great improvements can be made in the measurements made especially for the atmospheres of these planets.

In the alternative areas of use, security and defense come first. The risks posed by global security affect all infrastructure necessary for the production and transport of materials, energy, and information. The emergence of such risks for security is a motivation for the development of remote sensing and monitoring systems based on unmanned vehicles. This requires the development of powerful autonomous control technologies to co-ordinate a heterogeneous system connected to the same network that collaborates on a common task. The coordination of multiple heterogeneous systems and remote sensors with realistic applications is a promising approach to addressing this problem. It is considered that it is possible to use the herds formed by UAVs specially to provide border security and to create an air defense system-like structure against the attacks [17].

3. NATURAL DISASTER MANAGEMENT WITH MULTI UAV SYSTEMS

In natural disaster management, time is the most important parameter in saving the lives of people in need. The need for real-time information acquisition is essential to manage SAR missions. Considering the physical dimension of the disaster, it can be difficult for people to respond in a timely and healthy manner to the problem. Therefore, the most efficient and fast situational awareness that can be obtained in these disaster situations is acquired by air. To estimate the probability of the disaster, to react effectively to the disaster during the realization, the multiple UAVs communicating with each other for cooperation the UAV networks will be the most promising and powerful choice. Teams of UAVs can ensure discovery and mapping support, have structural evaluation, identify survivors and be station as an ad hoc infrastructure to connect mobile devices to the nearest network. The information about the number of structures which affected by disaster, the extent and damages of these structures, the situation of the infrastructure of transportation and estimated number of people who affected by the disaster can be obtained by using UAVs and following some determined steps [38].

As a result, research and development studies are done to manage natural disasters in an effective way. Recent studies on UAVs and swarm of UAVs make it an excellent candidate to play an important role in natural disaster management. Therefore, UAV systems have been getting more and more attention for disaster management in recent years [37].

3.1. Disaster Management Phases

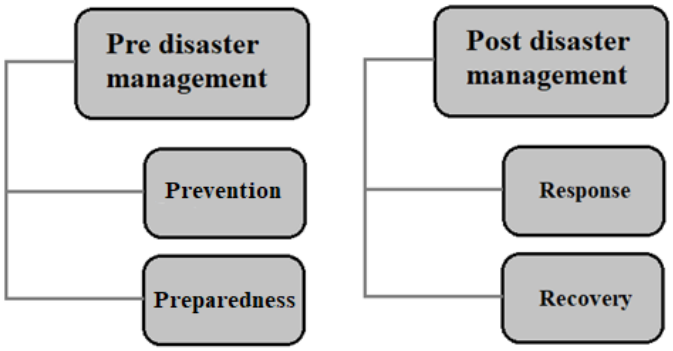

Figure 3.1. *Disaster management phases*

Natural disasters affect the life and development of humanity and happen frequently around the world. Therefore, it is important to investigate and understand the structure and stages of these disasters that affect humanity so deeply, to develop appropriate techniques and methods to respond to all different natural disaster types and to reduce their effects. Disaster management

phases, are used to identify, analyze, and divide disasters into processes to manage the natural disasters in an effective way. Disaster management phases can be defined like four-phases such as taking precautions against disasters occurring before the disaster, and being prepared for the situation, and responding to the situation during the disaster and managing the recovery process. These phases which represented by Alexander in [42] are illustrated in Figure 3.1.

The first step of the disaster management phases for the pre-disaster is the prevention step. The purpose of this step is to reduce the effects of disasters. Providing public trainings which are related with the critical information for the disaster, conducting risk analyzes for regions or creating warning codes are some of the examples for this step. The next step that can be followed before the disaster is the preparedness phase. The purpose of this step is being prepared on how to deal with a possible disaster. Effective plans, trainings, emergency drills and Early Warning System (EWS) are for preparedness phase.

The first phase for post- disaster is the response step. The purpose of this step is to reduce the negative effects and dangers caused by the disaster. It covers SAR missions and emergency services. The last phase is the recovery step. The damage that occurred in the disaster has been evaluated at this stage. Information which is obtained during the disaster will be used.

When disaster occurs, the most important and critical issue is human life and the first 3 days after the disaster are the most critical moments for human life. According to [43], the biggest problem during the disaster is communication and situational awareness. These problems significantly reduce the efficiency of the response step. According to [44], real-time information is among the most critical issues. Therefore, their study is on the location and navigation which are required for the emergency response teams. Although the order of necessity of stages is different for each disaster, all steps are critical for natural disaster management. Different technologies are used to increase the efficiency of the disaster management system. Communication and information sharing are significantly necessary to facilitate the coordination of disaster management teams about disasters. However, existing technologies are not used adequately in response to disasters [45].

3.2. Features of UAV Networks

UAVs will be the most efficient and smartest choice when it comes to natural disaster management but running multiple UAVs at the same time will not be enough for a successful SAR mission. The design offered in terms of the network is critical to the success of the management. The features that a successful UAV network should have are as follows.

Energy Efficiency- UAVs in the commercial market can stay in the air for about 20-30 minutes at a time. Therefore, in the case of a complex situation such as disaster management, the efficiency of these limited periods should be maximized. Topologies with optimized missions and reduced mobility can be successful in these complex missions.

Dynamic Topologies- Centralized placement optimizations may not coincide with the corresponding 3D airspace. Some unpredictable drafts, some inaccuracies in 3D modeling, and changing field conditions may require sudden and unexpected variations in the localization of UAVs. The protocols in the systems used must adapt to these situations in real time.

Multi-Target Periods- UAVs that are involved in natural disaster management may require more than one round charging. Such interruptions call the UAV back to the nearest charging center. Therefore, whether the same network will be maintained, or whether the entire topology will be proactively changed will be questioned [18]

3.3. Applications of UAVs for Natural Disaster Management

UAVs are utilized in various applications, during the natural disaster management. Some of these applications are given as follows.

Monitoring forecast and early warning – UAVs are used to predict the possible disaster with the information obtained through monitoring, to analyze the information obtained and to create an early warning system.

Merging and sharing information- UAVs help to combine information from different sources and to bridge the information that can be used in other applications for natural disaster management.

Providing logistics, evacuation, and situational awareness – Provides situational awareness by helping to gather information about the placement of injured persons by rescuers during the disaster and to obtain real-time information about the disaster area.

Standalone communication system- Because of the disaster, communication infrastructure lost its function and the communication has been damaged. Swarm of UAVs acting like base stations and they provide telecommunication for victims.

SAR missions- UAVs search the entire disaster area with an optimized sharing, trying to save the mobile or immobile victims who were injured during the disaster and needed help.

Evaluation of damage- UAVs provide the assessment of the extent of the damage caused by disasters through the information they have obtained by conducting video surveillance or in contact with other UAVs [7].

3.4. Proposed UAVs for an Example Scenario

In the example scenario of use of UAVs in natural disaster management, it would be wise to use a heterogeneous system with fixed wings and rotary wings. For a general view of the disaster area, it will be good to use fixed-wing UAV for fast field scanning. In this section we select two available commercial mini UAV platforms to be used in real life management scenarios instead of simulation.

The first recommended UAV is (fixed wing) eBee X which is the newest product of SenseFly, is one of the smartest candidates that can scan the disaster area in the most efficient way with the features shown in Table 3.1.

Figure 3.2. *SenseFly – eBee X Fixed Wing Drone*

Table 3.1. *Properties of eBee X*

Weight (incl. supplied camera & battery)	1.1 kg- 1.4 kg
Max Flight Range	47 km
Radio link range	3 km to 8 km
Speed	40-110 km/h
Wind resistance	Up to 46 km/h
Flight planning & control software	Supplied
Image processing software	Optional

After disaster scanning is done, vehicles, people or buildings at critical points are detected, quadcopters can be sent to provide real-time information flow from these points.

Figure 3.3.*DJI Phantom 4 Pro*

Table 3.2 illustrates the basic features of the DJI Phantom 4 quadcopter which is available on the market, to get real-time information acquisition from the disaster area.

Table 3.2. *Basic features of DJI Phantom 4 – Pro*

Weight (Battery & Propellers Included)	1388 g
Max Flight Time	Approx. 30 minutes
Max Flight Distance	14 km
Max Speed	72 kph (S Mode)
	50 kph (P Mode)
Battery	6000 mAh

According to Table 3.2, it is estimated that 4 quadcopters can be sufficient for continuous surveillance of a point in the disaster area. Therefore, the UAV station must have a storage area that can accommodate at least 4 Quadcopters and 1 fixed wing UAV. In addition, this UAV station must be equipped with a long-distance communication antenna, UAV battery charging system and electric generator.

It is assumed that GPS modules which are located on UAVs are reliable. The user or operator can adjust the navigation points of the UAV manually. Using the commercial UAVs for disaster management is logical because of with their advantageous features such as their cost, ease of use and availability. The studies which are done about natural disaster management with commercial UAVs proved itself to being usable. Therefore, a robust and reliable natural disaster management system can be created, albeit costly, with fixed and rotary wings.

4. NETWORKING ARCHITECTURE

Recently, the issue of Flying Ad-Hoc Network (FANET) that is an Ad-Hoc network between UAVs, has become a popular subject to research and develop in military and civilian areas because of the rising demands to UAVs. These networks are composed with only aerial devices which can communicate between UAV to UAV (U2U) and UAV to Infrastructures (U2I). FANETs can perform independently or by transmitting the flow which is taken from ground-based devices to a remote server [24].

In FANETs, UAVs should be able to communicate with each other to perform various defined tasks and services. The Figure 4.1 illustrated the connection which is provided with UAV based networking architectures for communication of U2U and U2I. Relaying U2U communications and getting network information are two basic process in FANETs. Furthermore, UAVs have two additional missions. The first one, they operate like remote access units to expand the range of infrastructures. Second, they create a dynamic network with multiple and mixed sources. Given the roles of UAVs in network architecture, two distinct modes should be allowed, such as U2U and U2I [24].

Therefore, one of these UAVs takes the act of being a gateway in the networking architecture, and this UAV is called the backbone UAV. The backbone UAV gets data from other UAVs with U2U. Thereafter, the backbone UAV transfers the data to the ground station using U2I communication [48].

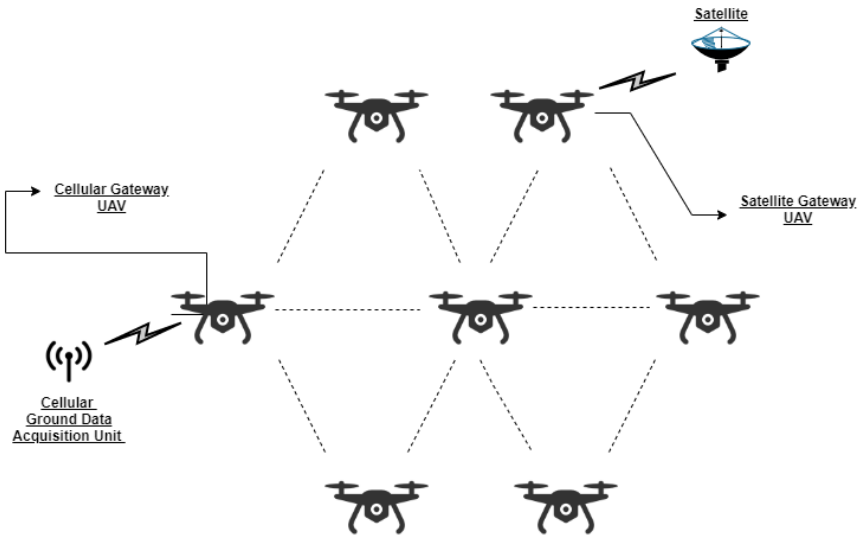

Figure 4.1. *UAV-to-UAV and UAV-to-Infrastructure Communication*

In [50], two sorts of networking architectures are offered for linking swarm of UAVs to each other such as centralized and decentralized which are shown in Figure 4.2. Centralized networking architecture includes the ground station as a central node. All the UAVs are directly connected to it. That is why, transmission of data between UAVs needs to be sent over the ground station. On the other hand, in the decentralized networking architecture, UAVs can contact each other straight ahead or indirectly. They do not have to connect with ground station. There are also presented three sorts of decentralized networking architectures, and they called as UAV, multi-group UAV, and multi-layer UAV Ad-Hoc network [51].

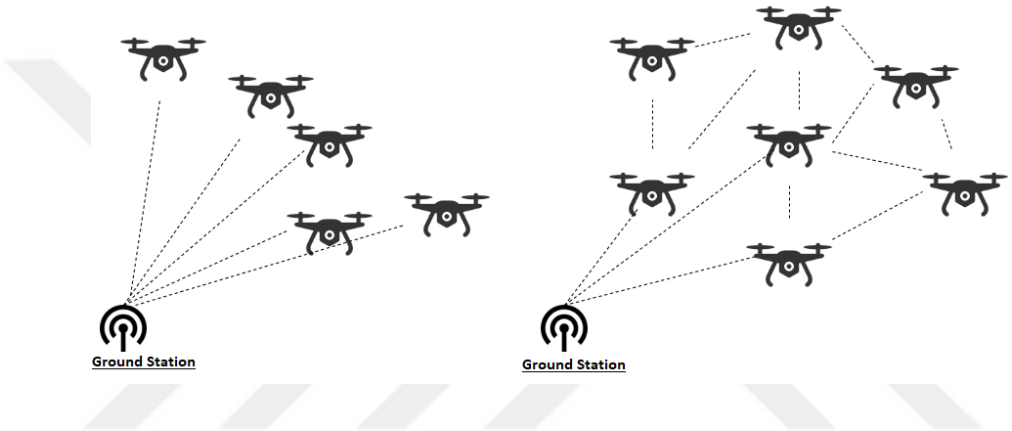

Figure 4.2. *Centralized and decentralized networking*

4.1. UAV Ad-Hoc Network

In that network, every UAV is involved to the information forwarding process for the other UAVs of the network as shown in Figure 4.3. The backbone UAV acts like a gateway between the UAVs and the ground station in this architecture. It is equipped with two different radios which are the low-power, short-range and the high-power, long-range. The backbone UAV uses low power short-range radio to communicate with the other UAVs and, high power long-range radio is used for communication between backbone UAV and ground station. There is only one backbone UAV which relates to the ground station in this networking architecture that is why the area covered by the network is extremely extended. Moreover, the transceiver attached on the UAV is lightweight and cost effective because of the distance between the UAVs is so small. That is why it is quite attractive to use for small sized UAVs [48].

On the other hand, the characteristics like speeds, heading directions, altitudes, and mobility patterns of all the connected UAVs should be the same to have more persistent network.

Consequently, it is the most appropriate for surveillance, monitoring operations, and other missions which requires a small number of homogeneous UAVs for deployment [48].

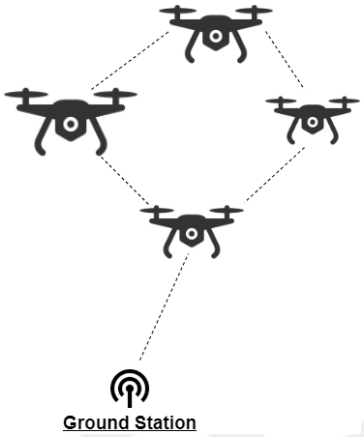

Figure 4.3. *UAV Ad-Hoc Network*

4.2. Multi-Group UAV Ad-Hoc Network

A multi-group UAV Ad-Hoc network is, as shown in Figure 4.4, a combination of a UAV Ad-Hoc network with centralized network architecture. In multi-group UAV Ad-Hoc network, UAVs within a cluster set up an Ad-Hoc network. Therefore, the backbone UAV of every cluster, is attached to the ground station in a centralized way. The communication between the UAVs that are in the clusters is ensured with UAV Ad-Hoc network while the communication between clusters is provided by the backbone UAV. The multi-group UAV Ad-Hoc network is most appropriate for the tasks which requires many heterogeneous UAVs. However, this networking architecture is not robust because of the nature of semi-centralized architecture [48].

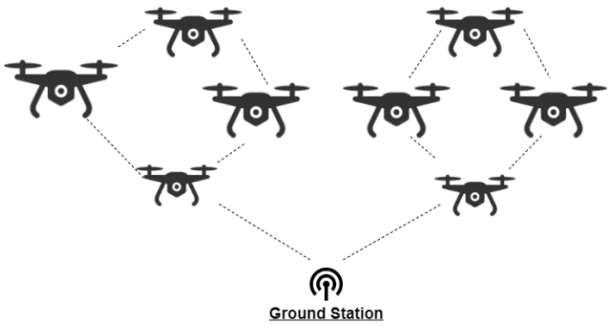

Figure 4.4. *Multi group UAV Ad-Hoc network*

4.3. Multi-Layer UAV Ad-Hoc Network

Multi-layer UAV Ad-Hoc network, shown in Figure 4.5, is alternative structure of networking multiple sets of heterogeneous UAVs. This network communicates to the under layer of the network. Backbone UAVs of all clusters are linked to each other and it flows under to upper. Moreover, there is just one backbone UAV for each cluster, and these backbone UAVs communicates with the ground station. Additionally, the information which is routed to ground station to decrease communication and the computation load on the ground station is hold by only ground station. That is why multi-layer UAV Ad-Hoc networking architecture is best suited for tasks which is requires many heterogeneous UAVs.

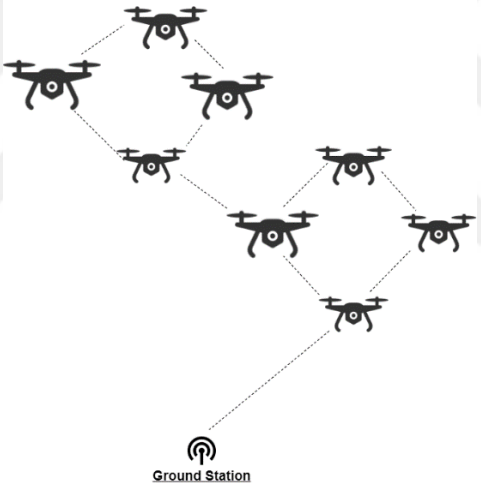

Figure 4.5. *Multi-layer UAV Ad-Hoc network*

As a conclude, a decentralized communication networking architecture is appropriate for linking multiple UAVs in FANETs. These communication architectures can ensure extended coverage for transmitting data. Furthermore, it can be said that for small number and homogeneous of UAVs, the UAV Ad-Hoc Network is best. Moreover, as it mentioned in the thesis, Multi-layer UAV Ad-Hoc Network's nature is decentralized, that is why it can be more appropriate for multi group UAVs. Also, this network can be admitted as robust in case of failure. Therefore, it is more elastic in supplying “on-the fly” communication network [48].

5. WIRELESS COMMUNICATION TECHNOLOGIES

In the previous chapter, several networking architectures between U2U and U2I are explained. Most of the wireless communication technologies may be the potential options to ensure flexible and reliable communication connections for the deployment of FANETs in a fast way with these architectures which are explained above. All the potential wireless communication technologies for U2U and U2I communications are investigated in this thesis are listed and compared in the following sections. Their main properties are also listed in this table. The type of the mission and the nature of the application is quite essential to choose the most suitable technology. However, almost all the wireless communication technologies can support the FANETs because of their low demand for control traffic.

Wireless communication technologies can be separated into two parts such as short- and long-range communication technologies. Wi-Fi, Bluetooth, and ZigBee are called as a short-range communication technology and they are utilized for short distance. Satellite, WiMAX and cellular are called as a long-range communication technology and they are used for bigger areas [48].

5.1. Short Range Communication Technologies

Short range communication technologies provide a wireless access in the environment which is close (ten to hundreds of meters). Additionally, it also presents light weight, cost effective and off-the-shelf communication connections due to their spectrum free (unlicensed) bands. It also offers a transfer of data from very small distances to a few hundreds of meters.

5.1.1. Wireless Fidelity (Wi-Fi) - IEEE 802.11

Figure 5.1. *The logo of Wi-Fi*

Wi-Fi is a short-range wireless communication technology which includes some specific standards to design Wireless Local Area Network (WLAN) in the 2.4, 3.6,5 and 60

GHz radio bands. IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, IEEE 802.11ac are the best choices for most of the FANETs applications to ensure the output which is required for big data transmissions such as videos and images. A Wi-Fi system which is designed for the data transmission provides a location- independent communication network access by radio waves between devices. The first IEEE 802.11b could transfer the data with the speed up to 11 Mbps. After that, IEEE 802.11a came up, followed thereafter by IEEE 802.11g. Both have the maximum speed up to 54 Mbps and the throughput of about 25 Mbps. The hardware of WLAN is built around IEEE 802.11g and it was embraced by business and consumers who are seeking higher bandwidth [52]. The following Wi-Fi speed standard which is IEEE 802.11n has been offering up to 108 Mbps bandwidth. Moreover, it is interoperable with the n-compliant devices because of being an industry standard [53]. After that, 802.11ac followed them. It can be said that, 802.11ac is a supercharged version of 802.11n. 802.11ac is dozens of times faster, and delivers speeds ranging from 433 Mbps (megabits per second) up to several gigabits per second. As a last, the next-generation 802.11ax Wi-Fi standard, also known as Wi-Fi 6, is the latest step in a journey of nonstop innovation. The standard builds on the strengths of 802.11ac, adding efficiency, flexibility, and scalability that allows new and existing networks increased speed and capacity with next-generation applications. The comparison of the IEEE 802.11 standards is listed in Table 5.1.

Table 5.1. *The comparison of the primary IEEE 802.11 features*

Standards	Approved date	Maximum data rate	RF band	Technique used	Channel Band width	Range
802.11	1997	1to2 Mbps	2.4 GHz	DSSS	20 MHz	100 meters
802.11a	1999	54 Mbps	5 GHz	OFDM	20 MHz	80 meters
802.11b	1999	11Mbps	2.4 GHz	DSSS	20MHz	100 meters
802.11g	2003	54 Mbps	2.4 GHz	DSSS, OFDM	20MHz or 40MHz	100 meters
802.11n	2009	600 Mbps	2.4GHz & 5 GHz	OFDM	20MHz or 40 MHz	140 meters
802.11ac	2014	1Gbps	5 GHz	OFDM	80MHz or 60 MHz	160 meters
802.11p	2010	27Mbps	5.9GHz	MIMO, Frame aggregation	10 MHz	1000 meters

The system of traditional Wi-Fi has about 100 m transmission range. However, the Ad-Hoc Networking can give the support to expand the range of transmission up to a few kilometers. Clients can explore and associate with Wireless Local Area Networks in the normal IEEE 802.11 networks. They can do that thanks to the announcements of access points [55]. Hereby, any device can behave as a client or as an access point. They could even be run by the same device at the same time. In [56], the performance measurement of Wi-Fi in terms of output, RSSI and the distance between the ground station and UAV is examined. As a result, applying that Wi-Fi networks to UAV-based communication networking is founded quite useful [48].

5.1.2. Bluetooth - IEEE 802.15.1

Figure 5.2. *The logo of Bluetooth*

Bluetooth is a short-range communication technology and it enables Wireless Personal Area Networks (WPANs). It utilizes the short wavelength radio frequency which based on the 802.15.1 communication standard to link with the multiple devices at the same time in a short

distance [58]. Moreover, Bluetooth is one of the communication technologies which operates in the 2.4 GHz band with the 10 to 200 m of communication range. There are various versions of Bluetooth technologies which have different values of data rate from 1 Mbps to 3 Mbps, however the data rate can reach up to 24 Mbps as a maximum. In the Bluetooth 4.0 specifications, Bluetooth Low Energy (BLE) was proposed by the Bluetooth Special Interest Group (SIG). The last model of the Bluetooth core specifications is the Bluetooth 5 [57]. There are lots of improvements such as in energy efficiency, transmission range, speed, and coexistence with the other technologies, which are mainly focused by Bluetooth 5. Also, Bluetooth 5 can broadcast richer throughput which goes far beyond the location data and includes URL's files and multimedia. According to the improvements in this technology, Bluetooth 5 is the potential good candidate for future FANETs in terms of the low cost and the low power deployment [48].

5.1.3. ZigBee - IEEE 802.15.4

Figure 5.3. *The logo of ZigBee*

ZigBee is also another short-range communication technology which enables wireless WPANs. ZigBee uses the low power radio frequency which based on the 802.15.4 communication standard. Generally, that technology is utilized in the low data rate applications which requires secure networking and high battery life. It is used for applications which apart from the internet connection and its distance ranging is changeable from 10 m to 100 m. ZigBee is cheaper and simpler rather than Wi-Fi and Bluetooth. It operates in the 2.4 GHz frequency band and it also has 250 kbps of data rate. There are 16 channels in ZigBee and each of them requires a bandwidth of 5 MHz [48].

In [58], localization of a quadcopter was presented using the ZigBee. The results of the paper show that using ZigBee is effective, easy deployable and viable for the localization system. In [59], ZigBee was used for position estimation and communication for UAV landings

by Jiang et al. The study also shows that, as an outcome, the accurate position estimation and the error have decreased significantly when ZigBee is used. In [60], a hybrid scheme was presented, and the ZigBee was used to implement an intra cluster communication in that hybrid scheme. The results of the simulation show that ZigBee is a good choice for low data rate FANET applications.

5.2. Long Range Communication Technologies

Long range communication technologies are used to transfer data communication services between two sights in larger distance as a carrier. These technologies can be very useful to communicate between UAVs and the between UAV and ground station. Existing long-range communication technologies will be analyzed as following [48].

5.2.1. WiMAX - IEEE 802.16

Figure 5.4. *The logo of WiMAX*

WiMAX is called as a Worldwide Interoperability for Microwave Access. It enables Wireless Metropolitan Area Network (WMAN). WiMAX, also known as 802.16, is a long-distance communication technology standard which utilizes high-frequency radio wave to get a high data rate. WiMAX is designed to provide both mobile and fixed broadband applications. It is utilized to get the internet connection nearly everywhere worldwide. WiMAX supports a data rate till 75 Mbps for the fixed and mobile applications. It is developed to ensure high-quality video and voice streaming with the required quality of service (QoS) [48]. According to [62], WiMAX is noted as the most convenient communication technology for rescue systems which are UAV based. In [63], they made a networking plan in terms of the position and the number of UAVs. In this research, the probability of calculating the dimensions and getting a specific QoS using WiMAX is demonstrated with the simulation results.

5.2.2. Long-Term Evolution (LTE)

Figure 5.5. *The logo of LTE*

LTE is another long-range communication technology. It presents safe wireless connectivity, high rate data and mobility which can increase safety and control when the vision is beyond the Line of Sight (LOS). It is optimized for Internet Protocol (IP) with changeable bandwidths of 20, 15, 10 and less than 5 MHz Although it can reach an acceptable performance in 30 km and ensure a reasonable performance till 100 km, its optimum size of cell is 5 km. Not surprisingly, using an established network of LTE for UAVs has increased in the recent three years [48]. In [64], LTE technology is used for low attitude UAVs. In this study, it is stated that LTE technology can increased the performance of network in disaster response scenarios which are UAV based. In [65], the effect of UAV based observation and video streaming over the LTE system is presented. Similarly, in [66], two different scenarios are considered such as UAVs work like a transmitting base station in the downlink or like a transmitting user equipment in the uplink using LTE network. This study emphasizes the requirement of essential alterations for a smooth integration of LTE based UAVs for present LTE network. In [67], the aerial radio connectivity's performance is examined in a rural LTE network. The outcomes indicate that in a rural LTE network, some mitigation schemes which are relatively less complex and practical of interference have a high potency for deployment.

5.2.3. Fifth Generation (5G)

Figure 5.6. *The logo of 5G*

The cellular mobile communication includes GSM (2G), UMTS (3G), LTE/WiMAX (4G) and as a latest fifth generation of wireless communication standard (5G). It has some major features such as reduced latency, enhanced system capacity, energy saving, energy saving and ubiquitous connectivity. These systems will have a speed of 100 gigabyte per second (GB/s) with a capability of stretching almost 1000 times [48]. Owing to such like properties, 5G is ready to use for crucial roles in UAV based systems. For example, in the situation of UAVs in a 5G communication network, less dynamic segments of the FANET architecture can be linked with the core network. That situation makes the providing of services like observation of multimedia streaming easier. In [69], a multi-layer architecture is presented with distributed properties which allows the integration of UAVs by next generation wireless communication networks. Moreover, in [70], overview of the last researches in the systems of UAVs communication which addresses the 5G technics from the aspect of the network layer, physical layer and joint communication, computing, and caching is handled. Also, in [71], the situation of carrying the base stations (BS) for supplying 5G network connectivity is explored for rural settings.

5.2.4. Satellite communication (SATCOM)

Satellite communication is another long-distance communication technology and it also known as SATCOM. It is utilized for propagating electromagnetic signals from ground stations to space stations or satellites. Different satellites use varied frequency bands in SATCOM such as L, S, C and X-bands etc. For instance, C-bands are still used in some systems and they use the 6GHz uplink band and 4 GHz downlink band. On the other hand, X-bands are used in the military systems and governmental systems and X-bands use the 8 GHz uplink band and 7 GHz downlink band [48]. In [72], the key features such as downlink of satellite, uplink transmission power of UAV and transmission rate of image were examined. It was also stated that the satellite relay reaches a bigger overlay range and ensures a wide-coverage and high-quality image transmission. In addition to that, in [73], the main and important problems which are behind using the satellite communication for image and video transmission with UAVs are emphasized. The high cost of data transmission and inadequate bandwidth are specified as a two essential issues.

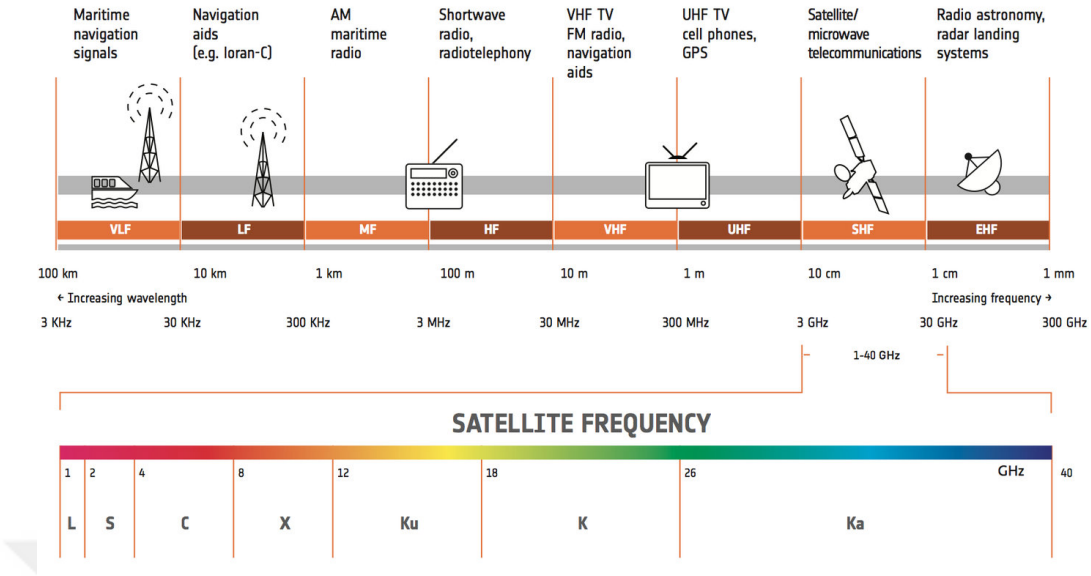

Figure 5.7. *Satellite frequency bands*

5.2.5. Vehicle to everything (V2X)

The short usage of V2X is called as a Vehicle to Everything. Its communication protocol which is IEEE802.11p, is an adjustment of IEEE802.11 standard for vehicles. The communication of V2X aims to improve efficiency and traffic safety. The new technology, V2X, can be used as solution for UAVs' present challenges like video streaming, management of air space in real time or collision avoidance. Normally, the use of V2X is a collision warning in forward. When any vehicle brakes in emergency, the system of V2X takes an action such as gets the vehicle's messages, reports a warning and slow down the brakes. This scene requires to have a reliable communication at high speed for V2X system. Also, it must be low latency and cover a wide range to give an enough time to response for drivers. All these properties are the same requirements for UAVs communication. That is why, the technology of V2X seems promising to tech transfer in UAV communication. For instance, in 2015, there were over the 400 UAV (drone) companies only in China. That is why, improving and differentiating themselves is quite important in this fast-growing market. As a clear example, DJI Lightbridge has been developed to have qualified video transmission system and that improvement led a big success of Phantom series.

Advantageous of V2X

V2X is a promising technology for wireless vehicle communications. Its data rate also is enough for filming HD video and changeable from 3 to 27 Mbps. It supports 5.9 GHz band in EU and USA. Also, many chips of V2X may works in 5.8 GHz ISM band and another much more bands such as 2.4 GHz. The combination of this wide range of unlicensed spectrum and powerful V2X tech makes this communication protocol an efficient candidate for UAVs' video transmission. The advantages of V2X technology are listed in below.

- *Long Distance*- Design target of V2X has adjusted much higher than the Wi-Fi products by their vendors to provide the long-distance requirement. Stable communication of IEEE802.11p links up to 4 kilometers at 5.8 Ghz is provided in the field tests.
- *Low Latency*- IEEE802.11p's MAC layer was simplified significantly to have a low latency. As a conclusion, V2X adds just a few milliseconds latency to the end to end latency.
- *Fast Reconnection*- In case of lost signal, the signal level is easily recovered thanks to simplified MAC layer. The communication link is immediately built by the simplified layer, it means there will be no additional delay in the situation of reconnection.
- *Less Interference*- When the link budget is calculated, the 2.4 Ghz is more advantageous in compared of 5.8 Ghz. (+7.7 dB) So, 2.4 Ghz can spread out more 2 times distance rather than 5.8 Ghz under the same situations. On the other hand, most of the devices are propagate their signals in 2.4 Ghz and they interfere each other. As a result, in this case the range has been decreasing dramatically.
- *High Velocity Tolerance*- Soon, UAVs will cross the barrier which is 100 km/h and this situation will cause some challenges in the communication system. This problem is solved by the V2X product perfectly because this product is designed and created to support vehicles which have high speed. It is proved in the field tests with speeds up 500 km/h.
- *Affordable*- The components of V2X system have already been obtained by the automotive industry. That is why, the improvement costs of V2X system has not an additional cost for UAVs. Besides, this development cost will decrease further with the growth of V2X market. This communication technology is cost effective and it meets whole requirements for UAVs' video transmission. V2X is much better than Wi-Fi in several issues and V2X presents its best as a performance.

Safety Issues of V2X

The concern of the safety issues is getting increase with fast grown market of UAVs. For instance, a DJI Phantom crashed to garden at White Houses in January 2015 and this issue immediately causes to put the safety problem of UAVs under the spot. V2X has also some solutions to solve that issue. As it is known, setting the no-fly zones by producer is a solution to keep away UAVs from crowded places and airports. On the other hand, to identify these areas is completely tough and keeping its accuracy over time is more challenging.

The basis of such a system may be standardized communication protocol where IEEE802.11p is a nice candidate, as UAVs can get the commandments from the air space controller. To limit the interference in UAVs, given channel is essential. There are 7 different channels which are separated in 5.9 GHz band for V2X services. There is still an argument in industry on sharing the channels with Wi-Fi. UAVs are becoming big and important part of the system of transportation and it will have an essential effect on public safety. That is why to open V2X channel rather than Wi-Fi to UAVs makes much more sense. UAVs and the air space controllers must identify each other from a distance, remotely, to prevent unauthorized manipulation. With this reason, the V2X safety system may be reused to design with the aim of providing a security in communication between UAVs and infrastructures.

Aviation industry already have the cooperative flying. For instance, Traffic Collision Avoidance System (TCAS). It questions the transponders of aircrafts and it negotiates the collision and avoidance strategies with them in case of danger. TCAS is quite expensive, huge, and power consumer. That is why it only appears in large air vehicles. Fortunately, these problems can also be fixed by the system of V2X. In the system of V2X, UAVs are required to bring out their current speed, position, and the other essential information to determine the risk of collision. V2X system's effectiveness is proved extensively in the field tests such as Safety Pilot in US and Drive V2X in EU. It is pointed out and reported that the system of V2X have the important potential to be beneficial in the case of collision avoidance [75].

5.3. Comparison of Communication Technologies

According to the above discussion, it can be said that short range communication technologies such as Wi-Fi, Bluetooth and ZigBee may be considered for FANET applications based on their range and output requirements. On the other hand, if the area is huge and these short-range communication technologies are not enough to provide required output demands then, long range communication technologies like WiMAX, LTE, 5G and Satellite may be more convenient [48]. All these communication technologies are listed and compared in Table 5.2.

Table 5.2. Comparison of existing communication technologies for UAVs

Communication Technology	**IEEE Standard**	**Frequency Band**	**Theoretical Data Rate**	**Indoor-Outdoor Range**	**Latency**	**Advantages**	**Limitations**
Wi-Fi [28]	EEM802.11	2.4 GHz	Up to 2 Mbps	20-100 m	Less than 5 ms	High speed and cheap	Limited range
	EEM802.11a	5 GHz	Up to 54 Mbps	35-120 m			
	EEM802.11b	2.4 GHz	Up to 11 Mbps	35-140 m			
	EEM802.11g	2.4 GHz	Up to 54 Mbps	38-140 m			
	EEM802.11n	2.4/5 GHz	Up to 600 Mbps	70-250 m			
	EEM802.11ac	5 GHz	Up to 3466 Mbps	35-120 m			
Bluetooth [44]	EEM802.15.1	2.4 GHz	Up to 2 Mbps	40-200 m	3 ms	Energy efficient	Low data rate
ZigBee [34]	EEM802.15.4	2.4 GHz	250 Kbps	10-100 m	15 ms	Low cost	Low data rate
WiMAX [37]	EEM802.16a	2 to 11 GHz	Up to 75 Mbps	Up to 48 km	30 ms	High throughput	Interference Issues
LTE [47]	LTE	Up to 20 MHz	Up to 300 Mbps	Up to 100 km	5 ms	High bandwidth	Expensive
5G [51]	5G	28 GHz	Up to 20 Gbps	Wide area	1 ms	High data rate	Expensive
Satellite [41]	Satellite	Up to 40 GHz	Up to 1 Mbps	Worldwide	550 ms	Wide coverage	High delay, high cost

6. CASE STUDY: EARTHQUAKE SCENARIO IN TURKEY

Considering the literature research, which is done in the thesis, it has been aimed to simulate a natural disaster management in a simulation environment. A well-designed simulator provides to rapidly test algorithms, design robots, perform regression testing, using realistic scenarios. Gazebo simulator [8] supplies these features and the ability to simulate in complex indoor and outdoor environments accurately and efficiently. That is why Gazebo environment has been chosen as simulation environment in the thesis. In the literature, there are many studies and research related with usage of UAVs and robots in Gazebo [81]. In this thesis, a scenario which belongs to the earthquake zone of a city in Turkey has been simulated in the simulation environment. The mission of the UAVs in the environment is to identify the people who are injured by the earthquake and transport them to the nearest hospitals, to provide a communication services (such as Wi-Fi connectivity) for all the victims in the disaster area and to ensure a healthy communication between the disaster area and the ground station. The main objects such as UAVs, casualty, hospital, and building are in the simulation scene. The representative sketch of the scene without the number of objects is given in Figure 6.1.

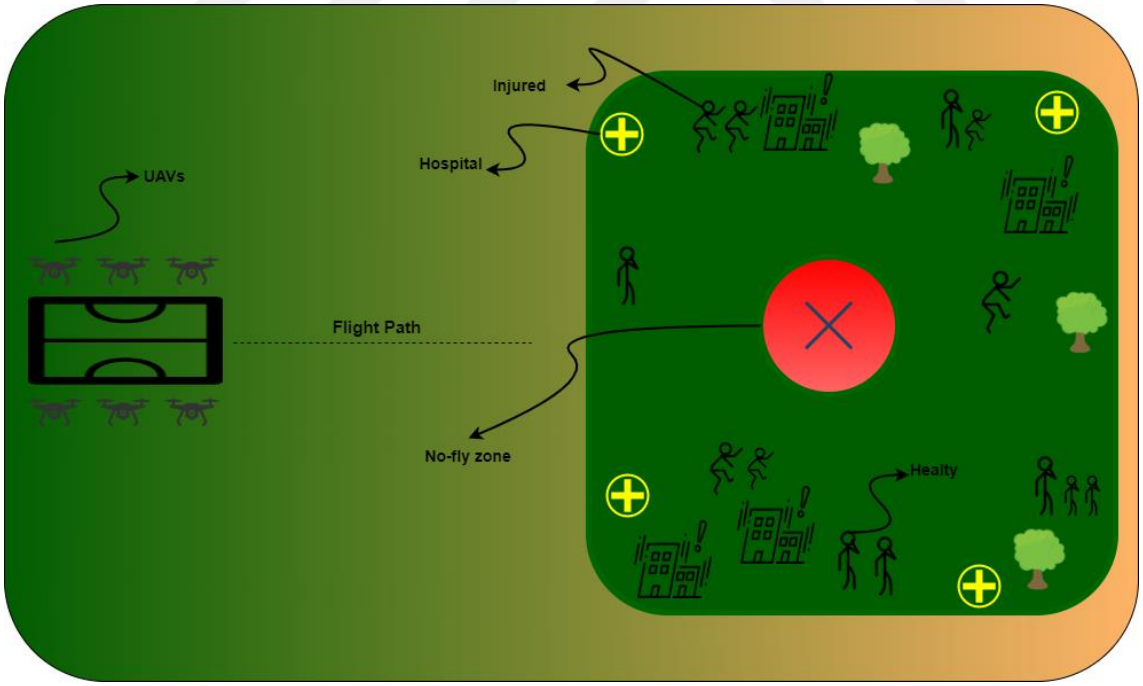

Figure 6.1.*Representative sketch of the simulation scene*

All the structures (UAVs, buildings, hospitals etc.) and environment which are used in the Gazebo are taken from the simulation competition of swarm of UAVs in TEKNOFEST 2020

[78]. Therefore, some solution methods are required to create natural disaster management with swarm of UAVs. In this thesis, the proposed algorithms are developed with Phyton code scripts to provide an efficient natural disaster management. The design solution is divided into subsystems to make problems more understandable in terms of natural disaster management phases (Chapter 3.1). These subsystems are given and explained as follows in order of occurrence under the headings of disaster management phases.

6.1. Prevention

Prevention is the first step of pre disaster management which is explained in the Chapter 3. This stage's responsibility belongs to the authorized persons. As it mentioned in its section, prevention covers all public trainings and risk analysis related with natural disasters.

6.2. Preparedness

This step is the second one of the pre disaster management phases. For this step, authorized people should offer effective plans and they should provide an early warning system. In this case study, as a preparedness step, deployment of UAV's airports should localize in the optimum areas to make reaching easy to any areas. Additionally, to provide early warning system, swarm of UAVs should scan the divided areas to check whether emergency situations such as natural disasters. Preparedness step includes some missions (for UAVs) to provide disaster management in our imaginary scenario. These missions are given as follows.

6.2.1. Formation flight

Formation flight is the coordinated flight of UAVs for achieving a specific mission. This flight is achieved by using a formation controller. Formation structures and UAVs' localizations are arranged by that controller. The usage of formation flight permits of handling most of the limitations imposed when using single UAVs. Therefore, using formation flight, increases the effectiveness of using UAVs to perform duties in practical life conditions. There are many studies in the literature that search and study the theory behind performing a successful and powerful formation flight controller for different types of UAVs [83].

In this section, UAVs take off the airport with defined prism formation flight. This formation flight is also illustrated in the Gazebo environment respectively in Figure 6.2 and Figure 6.3.

Figure 6.2.*UAVs have a prism formation flight in the Gazebo environment – front view*

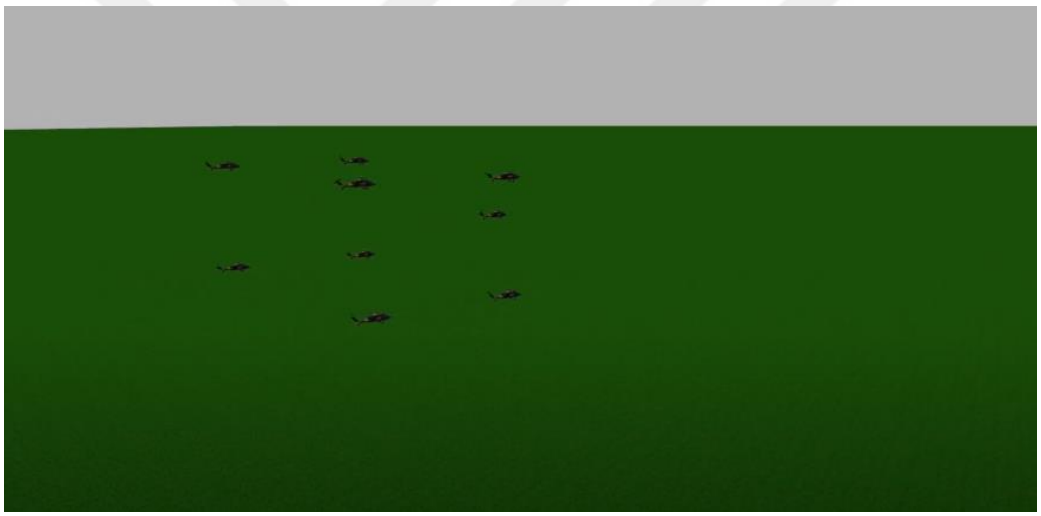

Figure 6.3.*UAVs have a prism formation flight in the Gazebo environment – back view*

There are different algorithms in the literature such as leader-follower, virtual structure, behavioral and consensual approaches [85]. In the Leader-Follower approach, a certain UAV is determined as the leader and the remaining UAVs follow the leader's path in a certain formation as followers. In this approach, unexpected maneuvers of the leader UAV are controlled by a controller to ensure the continuity of the flight and not to disrupt the formation. In the Virtual Structure control approach, UAVs behave like particles embedded in a solid structure. While the formation flight takes place, it moves by following the virtual points on a rigid structure [86]. Consensus action of UAVs can be defined as UAVs asymptotically obtaining a common dynamic procedure through the cooperation protocol. According to the

requirements of the covariates, consensus problems can be categorized as state compromise and output consensus issues [86].

The formation flight in our study was carried out by following the Leader-Follower approach. The flow chart of the algorithm used for the leader UAV and follower UAV is shown in Figure 6.4 and Figure 6.5.

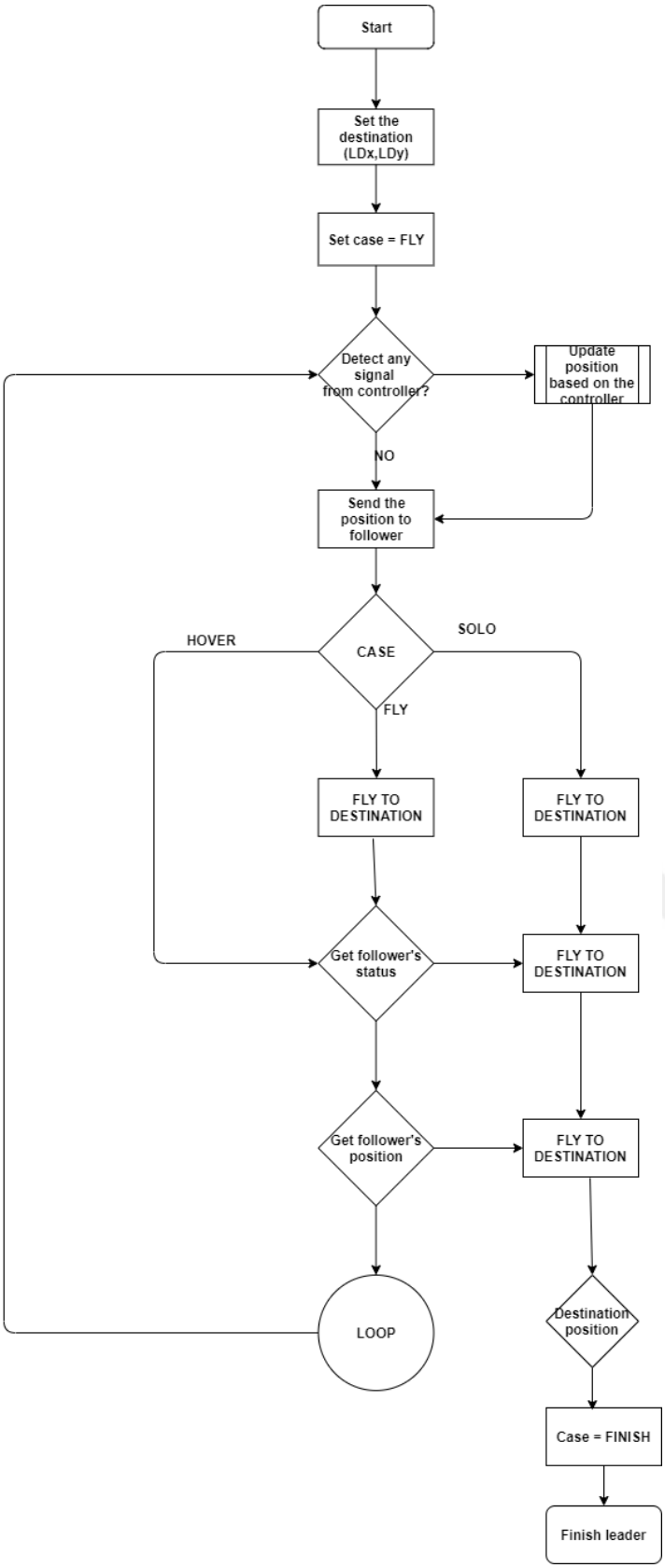

Figure 6.4.*Flowchart of Leader UAV's algorithm*

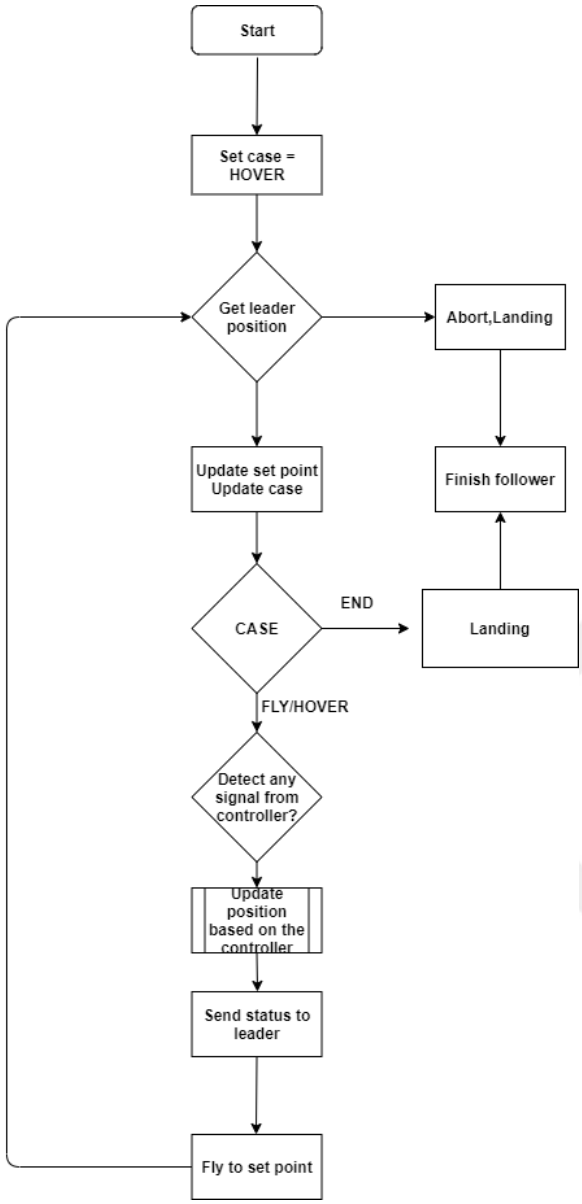

Figure 6.5. *Flowchart of follower UAV's algorithm*

6.2.2. Creating navigation route points

UAVs will optimally share the areas to be searched considering their capabilities and aerodynamic structures after arriving the defined areas with formation flight. By considering their capabilities and aerodynamic structures in the shared areas, navigational route points will be created, and UAVs will perform their search activities by going to these route points. Navigation route points will also be created in such a way that they can use the fuel in the most efficient way and maximize the communication system that UAVs will provide to the victims, in case of occurring disasters.

There are many studies in literature for dividing areas. In [87], sweep - line approach is used to divide operation area. In this algorithm, most appropriate UAV/robot is assigned for each subarea considering with their capabilities. On the other hand, the algorithm assumes that the UAVs/robots are located on the boundaries of the area and it is not totally realistic. In [88], heuristic algorithm is presented as an alternative method to dividing area. the results of this approach are quite promising; however, it has two major problem such as not having specific guarantee about the optimality of the area division and not taking into account of initial robots' position [89].

The route planning algorithm that we will use in this study should be able to divide the search area into sub-search areas and be shared between UAVs in the swarm system. The figure below (Figure 6.6) consists of 5 sub-search areas shared among 5 UAVs in a flock of UAV systems. UAVs, shares the determined area in an optimum way, starting from the center point. Each area bounded by blue lines are areas that have the almost same areas, divided into equal angles, under the responsibility of different UAVs. By increasing the number of UAVs in the swarm, the optimized areas are shown in the Figure 6.7, and Figure 6.8, respectively.

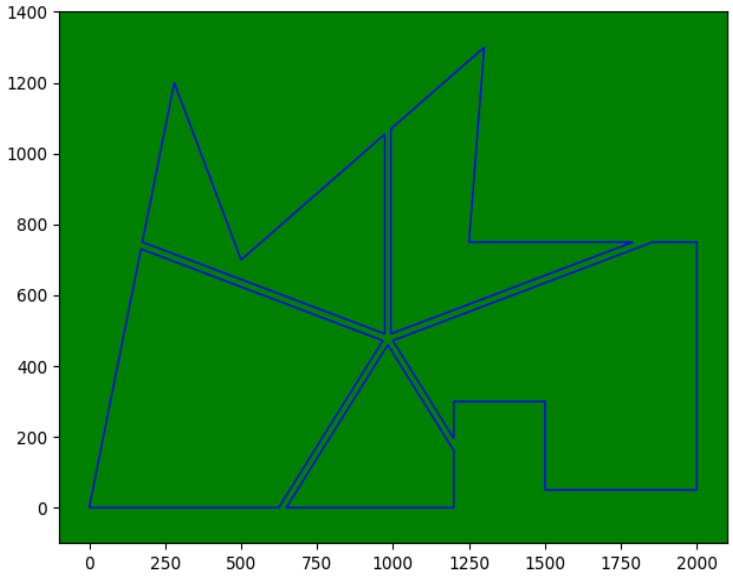

Figure 6.6. *Optimized area with 5 UAVs*

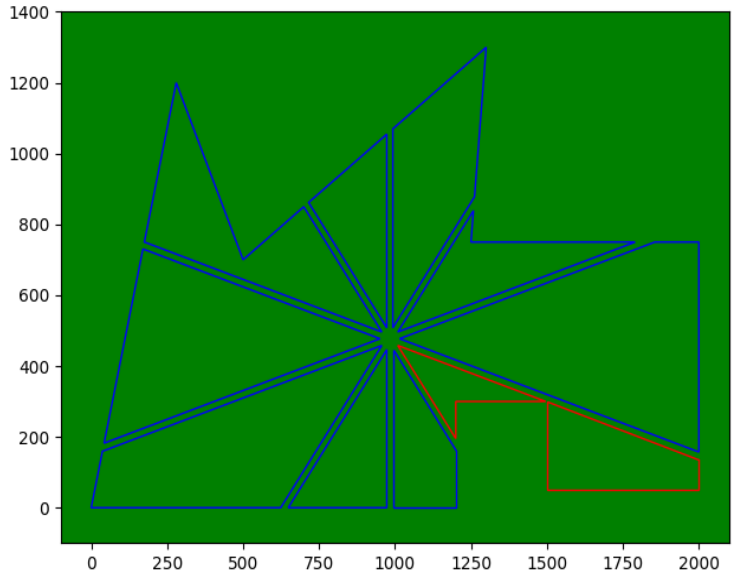

Figure 6.7. *Optimized area with 10 UAVs*

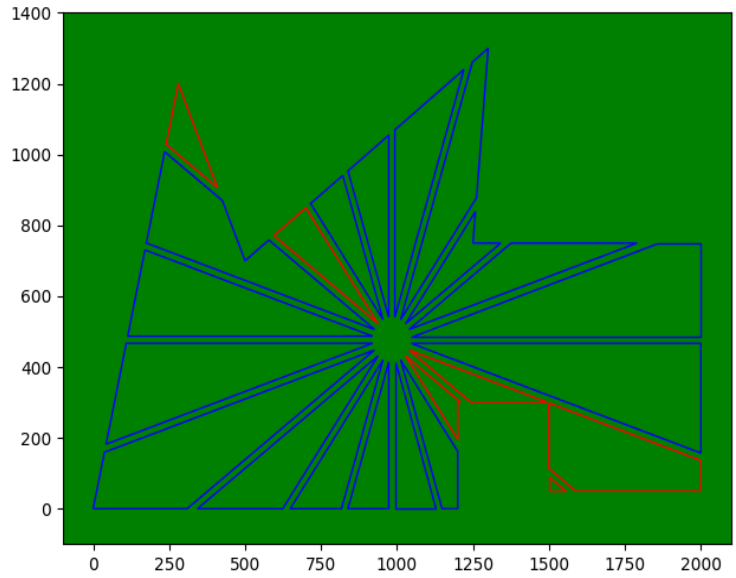

Figure 6.8.*Optimized area with 20 UAVs*

The algorithm that is used in this study in the system consisting of homogeneous UAVs divides the search area into sub-search areas by calculating that each UAV should be responsible for areas of equal size as possible and using minimum resources. This division begins with finding a representative point of the polygon (could be the center of mass of the area).

Then, from this point, two cutting lines are created and divide the polygon into two areas with the angle between them. If the small area is greater than the total area divided by the number of UAVs, this area is assigned to the relevant UAV and removed from the general search area. This cycle repeats as many as the number of UAVs in a multi-UAV system.

In the Figure 6.9, it is illustrated that UAVs share the disaster area in an optimum way in the environment. Each UAV is responsible of their own area and each UAV in the environment is red circled as it can be seen in the following figure.

Figure 6.9. *UAVs are sharing the disaster area in an optimum way in Gazebo environment*

6.3. Response

The first step of natural disaster management phases for post disaster is response step. Step of response covers all SAR missions to provide disaster management. Additionally, emergency services are provided in that step. The missions of UAVs to ensure the response step, are given as follows.

6.3.1. Field Scanning

The task of field scanning is critical for SAR missions. Also, it can be covered by both preparedness and response stages, however it has more share in response stage. Generally, field scanning with fixed wing UAV or UAVs is the following step after the scanning area in disaster management to check the area. This quick search determines whether injured in the disaster area or provides general information about the disaster area. As shown in the Figure 6.10, the UAV, whose starting point, and end point are determined, scans the area in the most optimal

way. Blue lines show the boundaries of the field and, the path which is followed by UAV is indicated by red lines. The UAV is represented by red point and it scans the area from beginning to end.

There are many approaches in the literature to planning and scanning field and the basic approaches are visibility graph, Voronoi diagrams and grids. In motion planning, a visibility graph is a graph of intervisible locations, typically for a set of points and obstacles in the Euclidean plane. Every node that is in the graph stands for a point location and every edge stands for a visible connection between them. If the line segment does not pass through any obstacle, an edge is drawn between them. When the set of positions lies in a line, this can be understood as a sequenced series [90]. Voronoi diagram is a division of a plane into areas that are close to each of a given set of objects. It can be easily said that these objects are just finitely many points in the plane (called seeds or sites). For each site, there is a suitable region consisting of all points of the plane closer to that site than to any other. These regions are called Voronoi cells. The algorithm follows the path which is set by these cells. [91].

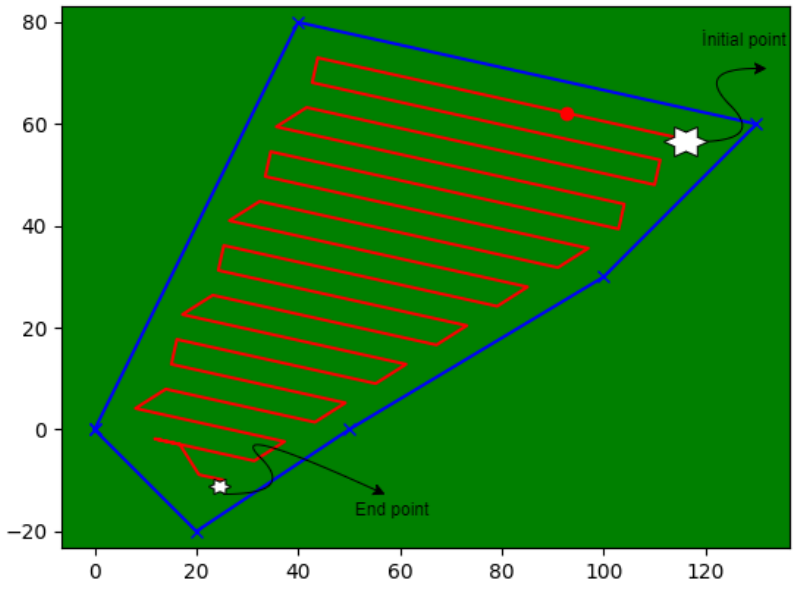

Figure 6.10. *Grid based path planning for UAV to scan the disaster area*

In this part, 2D grid-based coverage path planning method is used. In the grid-based path planning, the approach separates the field into a grid of uniformly distributed nodes. These nodes can be passable or non-passable. In here, coverage path planning is completed by passing all reachable nodes. The connectivity of grid is based on von Neumann neighborhood where

the UAV keeps going to the adjacent nodes step by step with directions of up, down, left, and right. This method is one of the easiest methods to utilize, but it may be computationally expensive for larger fields [76].

This method has been applied to the swarm of UAVs in the simulation environment and the field scanning in the environment has been completed with the Grid Based Coverage Path Planning Algorithm. The Figure 6.11 illustrated the scanning field with multiple UAVs in the environment. The UAVs who scan the disaster area are red circled in environment.

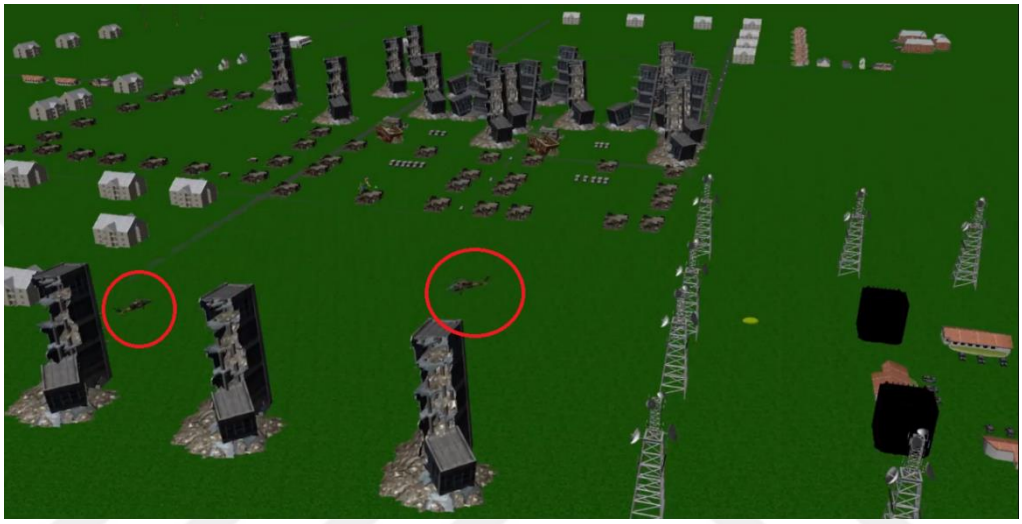

Figure 6.11.*UAVs are scanning the disaster area in simulation environment*

6.3.2. Personnel Identification, Tracking and Evacuation System

For UAVs, the monitoring and evacuation mission is another critical task for SAR missions, so for the response step as well. UAVs will check the data provided by the camera on them for the entire time they navigate. In case of detection of the casualty entering the field of view, the UAV will interrupt the search journey and the UAV will approach the position of the victim and descend to the evacuation altitude and take the victim to UAV. Afterwards, the closest and most appropriate hospital will be determined, and the personnel will be evacuated to this position. After evacuation, the UAV will head to the search navigation route point where it left off. The UAVs which delivers the wounded to the hospital and approaches to the wounded for evacuation are shown in Figure 6.12 and Figure 6.13.

Figure 6.12. *A UAV that approaches to the wounded for evacuation*

Figure 6.13. *A UAV that delivers the wounded to the hospital*

6.3.3. Telecommunication System

Providing emergency services is also included in response step. Communication service is one of the UAVs' tasks to be done for the response step as emergency services. Natural disasters can damage or even destroy existing communication networks during the disaster. In such natural disaster scenarios, communication is critical among rescue teams and casualties to manage the disasters. Therefore, the need for a fast and robust emergency communication system arises. In this context, UAVs are a smart solution to provide fast and reliable communication. Because at the same time, this system should provide low delays and rapid adaptation to the environment. To provide this system, UAVs are placed as mobile air base stations to provide broadband connection to areas whose communication infrastructure is damaged. UAVs can provide full coverage to any given area as soon as possible. In the scenario

used in the thesis, UAVs can communicate to healthy victims in the disaster area by flying from a certain altitude. As shown in Figure 6.14, each UAV acts as a base for survivors within a certain radius area in the areas where they fly. Also, providing telecommunication service in the environment is illustrated in Figure 6.15.

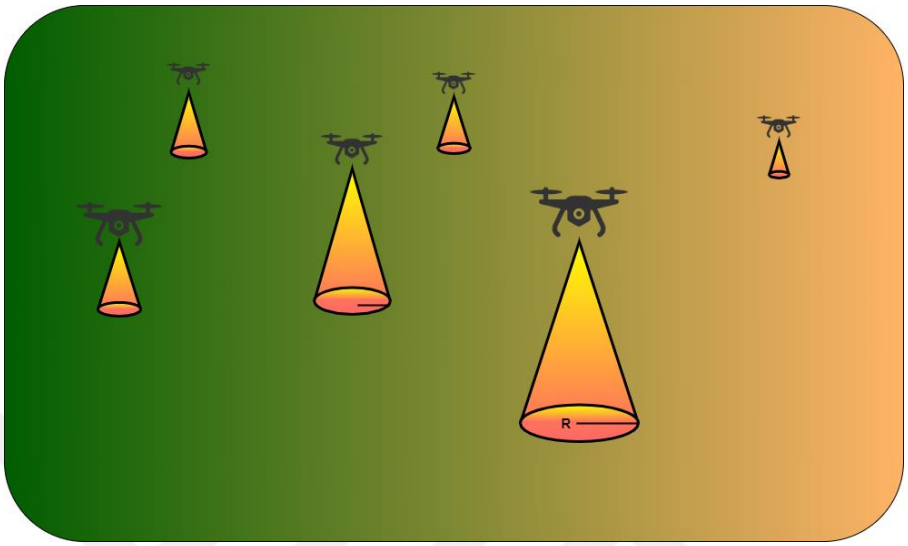

Figure 6.14. *Sketch of the UAVs' coverage for telecommunication service*

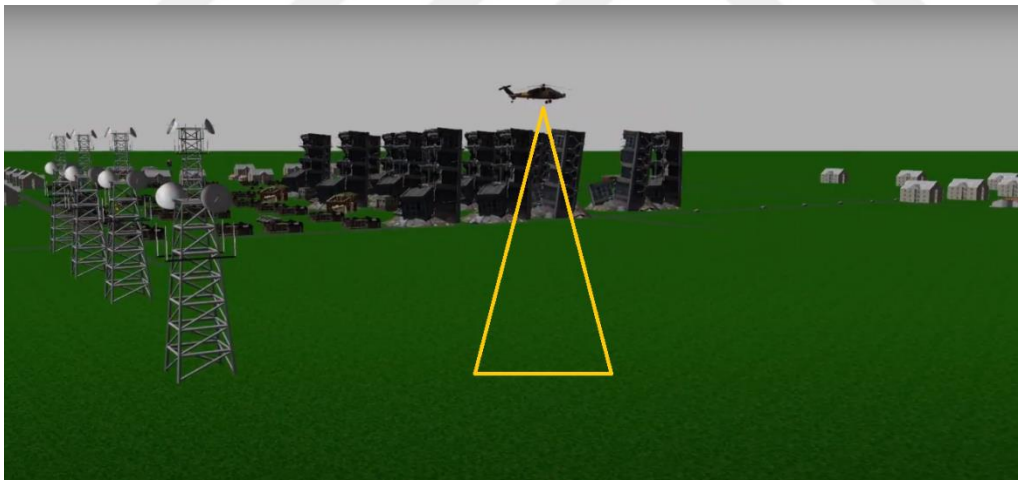

Figure 6.15. *UAV provides a telecommunication service in the Gazebo environment*

6.3.4. Autonomous Waypoint Navigation and Obstacle Avoidance System

There will be some requirements to complete the missions for response step. Avoiding from the obstacles when navigating in the area is important one of these requirements. In the simulation environment, a controller has been developed to enable UAVs to make autonomous

navigation from point to point. The developed navigation system allows the UAVs to point to the 3D coordinate point that will provide the latitude, longitude and altitude values entered. The navigation system consists of two subsystems, such as low and high resolution. The low-resolution navigation system brings UAVs from one point to another at a certain error distance. In cases where it is necessary to go to a point where the 3D position is given and hang in the air (take-off, landing, injured evacuation procedures, etc.), a high-resolution navigation system is used. Figure 6.16 shows a low autonomous UAV that goes to the center of the simulation environment with a certain error distance with a low-resolution navigation system.

Figure 6.16. *An UAV with autonomous navigation*

While UAVs autonomously navigate, there will be some obstacles in natural disaster management scenario that the UAVs should avoid, to move away from the obstacle on the flight route by maneuvering and return to the flight route when the obstacle passes. In the simulation environment, these obstacles are designated as static obstacles which are no-fly zones and high-rise buildings and as dynamic obstacles which are other UAVs in the swarm. UAVs avoiding these obstacles by making various maneuvers will prevent UAV from breaking and will work stably. There are many studies in the literature on the escape of mobile robots from the obstacle. As a result of various researches, it has been concluded that the most suitable method for the use of UAVs as single and multiple is the Dynamic Window Approach to Collision Prevention [77] method and this method has been preferred for UAVs to avoid obstacle [84].

The method includes a high-performance obstacle avoidance proposal, for mobile robots moving at even high speeds. The algorithm takes the initial coordinates and course angle of the

mobile robot as input. It controls the mobile robot by giving the acceleration (also its speeds) and the route angle in the relevant angles to go to the desired point as the output. During this process, inputs and outputs go through a filter that considers the obstacles that need to be opened.

The obstacle avoidance system that will be developed in UAVs will be created as the implementation of this algorithm and the algorithm will be fed with static and dynamic obstacles and UAVs will be avoided from the obstacles. While creating the obstacle avoidance system, the navigation system will be based on and will be customized for use in the swarm concept. A subprocess will calculate the UAV's continuous motion vector and check if this vector is approaching to a static or dynamic obstacle. In case of critical UAV - obstacle approach, this system will be activated, and obstacle will be avoided. When the motion vector is not blocked by any static or dynamic obstacle, the system will be disabled; normal navigation will continue.

The following figures that are Figure 6.17, Figure 6.18, and Figure 6.19 are showed the outputs of Dynamic Window Approach to Collision Prevention Algorithm. In the first figure, black points represent the obstacles. UAV starts from the initial point by tracking the path which is shaped according to the obstacles. UAV and end point are red circled in the figure. Additionally, in the last figure (Figure 6.19), followed path is illustrated by red line.

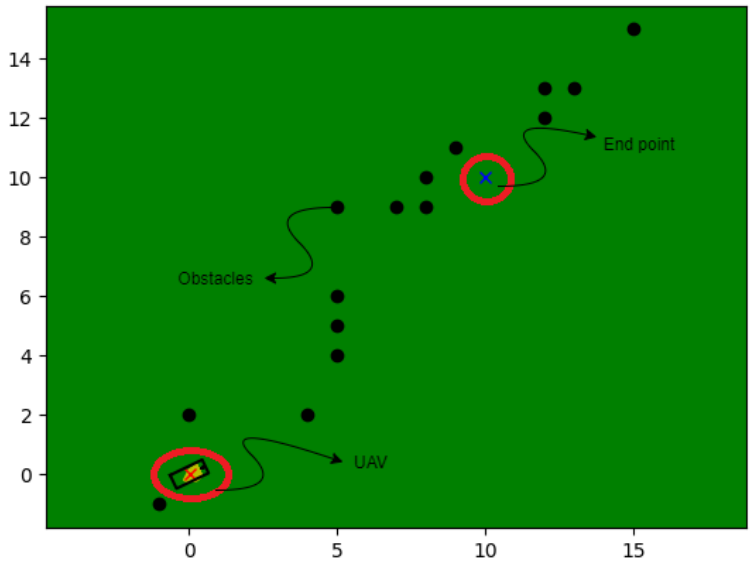

Figure 6.17. *Route Planning Algorithm that Scans a Field to Avoid Static Obstacles*

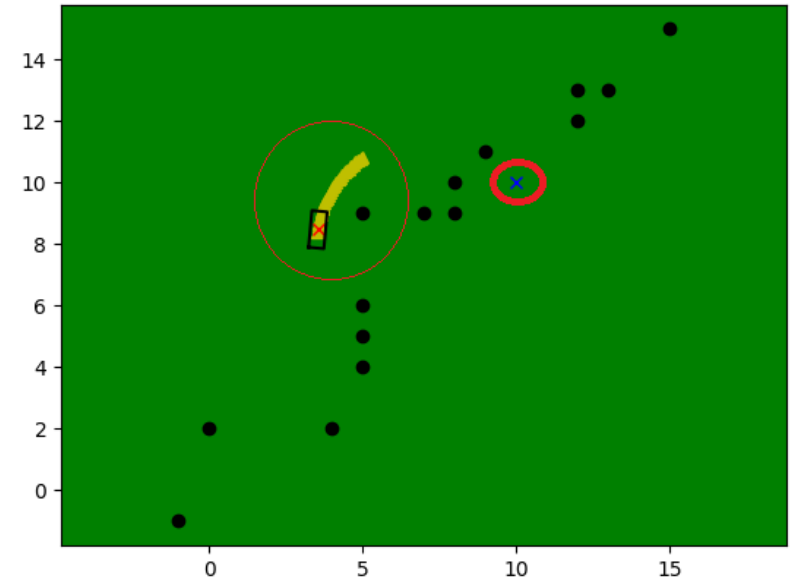

Figure 6.18.*UAV on the way to arrive target by avoiding the obstacles*

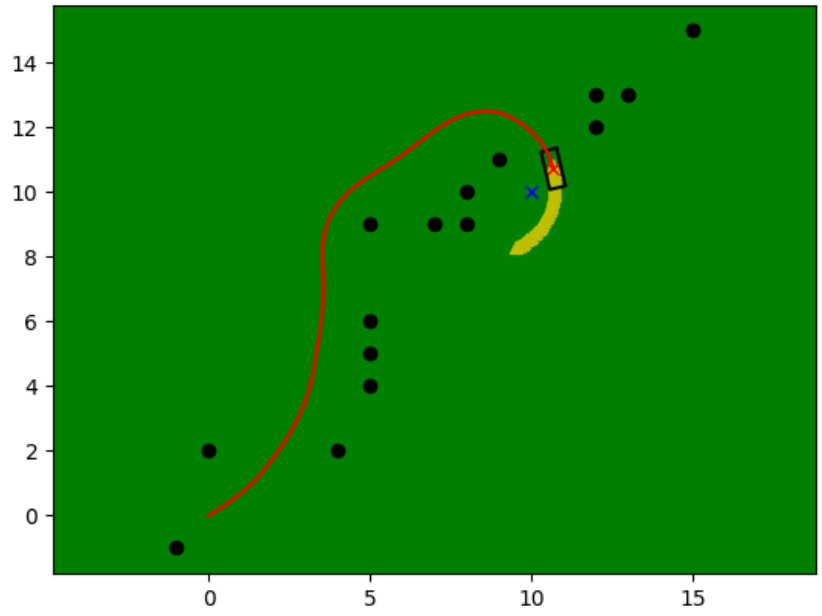

Figure 6.19. *Route Planning Algorithm Completed Area Scanning*

As an example, in the simulation environment the field of base stations are identified as no-fly zone areas. UAV could use the short path to arrive the yellow point if there was not no-

fly zone. Instead of that, it follows another path to get the destination as it is illustrated in Figure 6.20. The followed path is illustrated by yellow line and the UAV is red circled in the figure.

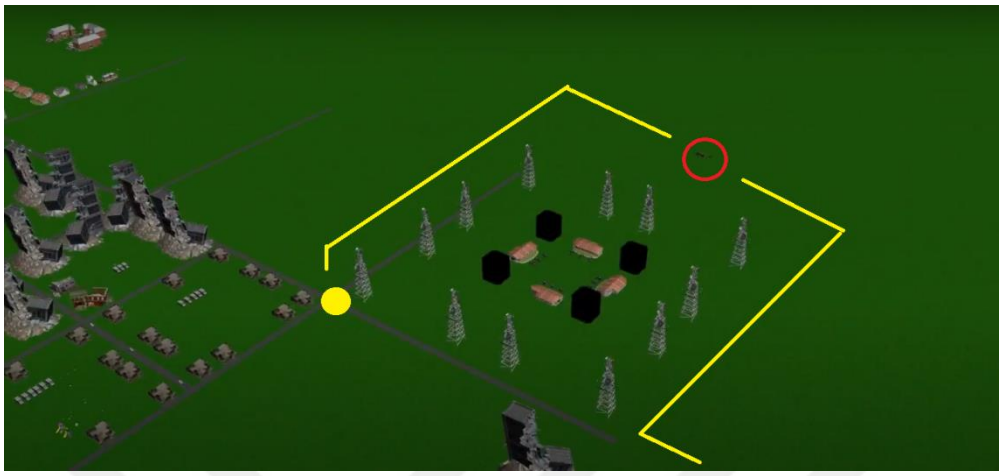

Figure 6.20. *The UAV is escaping from the no-fly zone to arrive the destination in the Gazebo environment*

6.4. Recovery

The last stage of the disaster management phase is recovery step. In here the damage that is occurred because of the disaster is evaluated by authorized persons with the information which is taken by UAVs during and after the disasters. UAVs can keep going to scan the field in case of being needed to obtain extra data from the disaster field.

Open Issues

Although there are still some open problems and challenges in using Unmanned Aerial Vehicles, they are one of the best technology options available in emergency scenarios. The listed issues are still working on with UAVs to build a more systematic and useful system. In general, the issue of power supply and processing power limitations continues to be a problem for UAVs when needed, on specific issues. In fact, although there are many studies in the literature on electricity generation techniques, but this is not enough in practice. At the same time, UAVs still cannot effectively cope with their maximum physical load and maneuverability in harsh conditions.

On the other hand, if the swarm of UAVs are planned to use in natural disaster management, then the system must handle with following issues. Unsustainable power supply, unreliable communication channel, deployment in harsh conditions, heterogeneity of data sources, and unexpected node failures are some of these issues.

7. RESULTS AND CONCLUSION

In the thesis, the aim is to focus on the role of multiple UAVs in natural disaster management. A comprehensive literature research about the swarm of UAVs' advantages, usage areas, roles in natural disaster management, usable networking architectures and existing wireless communication technologies is conducted.

A hypothetical earthquake scenario in Turkey was simulated in the Gazebo environment, considering the thesis research. In the environment, which is managed with Phyton code scripts, the design solution is divided into subsystems and they are presented and explained in order of disaster management phases. For each system, a few algorithms are examined and some of them applied in their section. For formation flight systems, leader-follower, virtual structure, and consensual approaches are introduced and compared. According to this comparison, leader – follower algorithm is chosen and applied for formation flight of UAVs. The scenario is set to have leader and followers for being most appropriate for this algorithm. Also, sweep – line, heuristic and route planning algorithm are introduced to divide disaster area for UAVs. Route planning algorithm is chosen and implemented to these UAVs in the Gazebo environment, because of being most appropriate and non-complex algorithm for homogeneous UAVs. As a last, for field scanning, the methods of visibility graph, voronoi diagrams and grids are introduced to plan and scan the path. In the scenario, disaster area must be scanned from beginning to end in most efficient way in the part of field scanning system, that’s why grid-based algorithm is chosen to have the most efficient results by scanning with UAVs. These algorithms are listed in Table 7.1.

Finally, unsolved issues and challenges which are about the multiple UAVs in emergency management are mentioned. Although UAVs have proved to be a successful tool in emergency scenarios, their use has not become widespread due to the obvious issues and challenges in disaster management. This thesis aimed to be one step closer to the future system.

Table 7.1. *The proposed algorithms for defined systems*

	Formation Flight	Area Dividing	Path Planning
Leader-Follower Algorithm [92]	x		
Virtual Structure Algorithm [95]	x		
Consensual Algorithm [86]	x		
Sweep – Line Algorithm [97]		x	
Heuristic Algorithm [91]		x	
Route Planning Algorithm [101]		x	
Visibility Graph Algorithm [90]			x
Voronoi Diagrams Algorithm [91]			x
Grid- based Algorithm [76]			x

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