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Dynamically Controlled Drones based on Software Defined Networking

A Thesis

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By

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(إِنَّمَا يَخْشَى اللَّهَ مِنْ عِبَادِهِ الْعُلَمَاءُ)

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Dedication

To the most beautiful blessings that God gave me, my son **(Mohammed Ahmed Zaki)**, on his first birthday

Acknowledgement

In the name of God, Most Gracious, Most Merciful

First and foremost, I thank God Almighty for His innumerable blessings ... My God, to you be praise and thanksgiving until praise reaches its limit ... And Your praise and grace have no bounds. Praise Allah for always helping me to achieve my aims.

My great thanks and gratitude to all in the College of Information Technology at the University of Babylon, and especially to the Department of Information Networks, head and members. Thanks and gratitude go to the honorable supervisors for their support in completing this work.

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I would like to express my wholehearted thanks to my family for the unlimited support, encouragement, love, and great sacrifice they provided me also for their patience, and help to me during the work.

My great gratitude to the Iraqi Ministry of Interior, which gave me this opportunity... and my thanks to all the officers of this ministry and the relevant directorates, especially the Directorate of Civil Status, Passports and Residence, to which I belong.

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Eng. Ahmed Zaki Wafi

Abstract

Drones are flying robots that have the ability to travel hundreds of kilometers and can be controlled remotely or fly autonomously by using software-controlled flight plans. In the bygone years, drone or also known as unmanned aerial vehicle (UAV) technology has developed very quickly and has been vastly used in martial operations, medicinal rescue, ecological monitoring, and other fields. Simultaneously, Software-Defined Networks (SDN) are the upcoming widespread, trustworthy, and flexible networking for the future. The programmability and center control system of the SDN network enticed many researchers, scholars, and manufacturing companies to make research and execute it.

There are many problems that the drone faces when it is working as a single because it is considered a single point of failure and which makes it easy to destroy and steal. At the same time, there are many challenges facing drone networks, resource management, and power-consuming are considered major problems faced in the drone swarm.

In this thesis, designed and built a network of drones based on SDN technology to use this network in multiple fields and applications. Where the drones act as a node of the network to collect data in the data plane and in the control plane we have an SDN controller located in the ground station. Furthermore, a collector has been added in this plane, which is a drone that works as a channel to connect the network nodes with the SDN controller. Besides, a protocol that performs synchronization between network collectors has been proposed. The proposed network is simulated using OMNET++.

The proposed system was evaluated based on throughput, packet delivery ratio (PDR), data drop rate, delay time, packet losses, and drone power consumption. The results obtained showed that by building the network based on the SDN architecture, there is an improvement in network management and energy consumption.

Table of Contents

Dedication I

Acknowledgement II

Abstract III

Table of Contents IV

List of Tables VII

List of Figures…………………………………………………………... VIII

List of Abbreviations ………………………….…………………………IX

Declaration Associated with this Thesis..X

CHAPTER ONE GENERAL INTRODUCTION

1.1 Background and Motivation …………………………………………… 2

1.2 Related works ……………………………………………...……..4

1.3 problem statement………………………………….……………… 6

1.4 Aims of the thesis…………………………………………………....7

1.5 Thesis Contribution……………………..…………………………...7

1.6 Thesis structure ………………………………………………………..8

CHAPTER TWO BACKGROUND AND THEORETICAL

2.1 Overview… ………………………...……………………………….. 10

2.2 Drone definition and history………………………………………… 10

2.3 Classification of drones………………………………………………..12

2.4 Applications of drones……………………………………………...…16

2.4.1 Drone applications in Aerospace…………………………………17

2.4.2 Drone applications in Commercial.............. 17

2.4.3 Military Applications………… 18

2.4.4 Civilian Applications.............. 18

2.5 Drone Energy Resources…………………………………………...19

2.6 Network of Drones 20

2.7 Communication of Drones networks……………………….…………21

2.8 Drones networks challenges…………..…………………….…….…24

2.8.1 Mobility……………..24

2.8.2 Adaptation…………...25

2.8.3 Reliability……...……...………………………………………….25

2.8.4 Scalability...25

2.8.5 Latency.......... 26

2.8.6 Bandwidth…………… 26

2.8.7 Energy and power-consuming…………… 26

2.9 Software Defined Network………………..…………………….………27

2.10 Software-Defined Drone Network ………………..…………………28

2.11 Advantages SDN for Drones Network ……….……………………..29

2.12 Architecture of Software-Defined Network…………………………30

2.12.1 Infrastructure layer ……………………………………….……...31

2.12.2 Control layer……...31

2.12.3 Application Layer ………………………………..…………32

2.12.4 OpenFlow Protocol ……………………………….…………..33

2.13Evaluation Metrics ……………………………………………..….34

2.14 Implementation and Simulation Tools………………………………35

CHAPTER THREE PROPOSED SYSTEM

3.1 Overview……………………………………………………..........40

3.2 The proposed Dynamic Software Defined Drones Networks………...40

3.3 The proposed Network Architecture………..………………………..41

3.3.1 Drones as the Data plane devices……………............................43

3.3.2 Collector Drones………. 43

3.3.3 Controller……………. 44

3.4 The proposed System Steps and Configurations…… ..………………45

3.4.1 The proposed Drones Environment Setting……..........................45

3.4.2 Network Elements Configurations..46

CHAPTER FOUR IMPLEMENTATION AND RESULTS

4.1 Overview……………………………………………………….…….…..50

4.2 Implementing proposed System in OMNET++………...……………..….50

4.2.1The first case study of 6 Drones Network…………......................53

4.2.2The second case study of 10 Drones Network…………….….......56

4.2.3The third case study of 20 Drones Network…………… 59

4.3 Building a network that contains more than one collector…………... 63

4.4 System Comparisons …………………………………………………63

CHAPTER FIVE CONCLUSION AND FUTURE WORKS

5.1 Conclusions………………..………………………......……………..69

5.2 Suggestion future Works………………..……………………………70

References ………………………………..……………...……………71

List of Tables

Tables No.	Tables Title	Page No.
2.1	Military drone's categorization based on their weight	13
2.2	Drones' categorization based on their weight	13
2.3	Drones' categorization based on weight and flight range	14
2.4	Compared algorithms and approaches for drone networks	24
2.5	Some of SDN controller	32
4.1	The main configuration of the used system in OMNET++	51
4.2	SDN controller physical layer	52
4.3	Controller MAC layer statistics	52
4.4	SDN controller battery statistics	53
4.5	Simulation results of 6 drones nodes in the networks	54
4.6	The results of 10 drones in the network	58
4.7	The results of 20 drones in the network	61
4.8	System comparison of one collector	64
4.9	System comparison of two collector	64
4.10	System comparison with related work	67

List of Figures

Figure No.	Figure Title	Page No.
2.1	Spectrum of drones from UAV to SD	15
2.2	Pictures for some type of drones	15
2.3	Different types of drone applications	17
2.4	Drone civilian applications	18
2.5	Communication technology's potential with drones	22
2.6	Software defined network architecture	30
2.7	OpenFlow Model	34
3.1	The block diagram of the proposed system steps	41
3.2	Architecture of drone network based on SDN	43
3.3	The proposed network topology	44
4.1	The proposed content fields of SDN-drone network	51
4.2	Network topology of the first case study	53
4.3	System statistics of the first case study (6 Drones Network)	55
4.4	Evaluation parameters of 6 drone nodes in the networks	56
4.5	Network topology of the second case study	57
4.6	System statistics of second case study (10 drones network)	58
4.7	Evaluation parameters of 10 drone nodes in the networks	58
4.8	Network topology of the third case study	60
4.9	System statistics of the third case study (20 drones network)	62
4.10	Evaluation parameters of 20 drone nodes in the networks	62
4.11	The used system comparisons among three case studies	65
4.12	Log File of the proposed system	66

List of Abbreviations

Abbreviation	Description
ABC	Optimized artificial bee colony
AFAR	Adaptive forward area based routing-algorithm
API	Application programming interfaces
DSDV	Destination-sequenced distance-vector
GIS	Geographic information systems
HPP	hybrid path planning
IACO	Improved ant colony optimization
Li-PO	lithium power
MAV	Micro aerial vehicles
NAV	Nano aerial vehicles
OF	OpenFlow protocol
ONF	Open networking foundation organization
ONOS	open network operating system.
PAV	Pico aerial vehicles
PRM	probabilistic roadmap
QoS	Quality of Services
RMICN	Router- movable information-centric networking
SD	Smart dust
SDN	Software-defined networks
SSL	Secure socket layer
TLS	Transport layer security
UAV	Unmanned aerial vehicles
WiMAX	Microwave access network
µUAV	Micro unmanned aerial vehicles

List of Thesis Related Publications

The work presented in this thesis has been published as below.

(First Paper)

Name of Journal: Webology Journal

Paper Title: Building flexible drone networks based on SDN

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Chapter one

General Introduction

1.1 Background and Motivation

Drones are flying robots that are also known as unmanned aerial vehicles (UAVs) which fly hundreds of kilometers and small drones that fly in confined spaces [1]. In other words, aerial vehicles that do not carry a human operator, fly remotely or autonomously, and carry lethal or nonlethal payloads are deem drones [2]. Although the correct date of the first successful UAV flight is not clear, some circles claim that the history of UAVs dates back to 1849 A.D, when the Austrians launched 200 pilot-less balloons filled with explosives against the city of Venice [3].

Advances in fabrication, navigation, remote control capabilities, and power storage systems have made possible the development of a wide range of drones that can be utilized in various situations where the presence of humans is difficult, impossible, or dangerous, also gained very great importance in practical practices because they are easy to set up and in some cases low costs for purchase and maintenance purposes. And due to the great interest in drone applications which led to the invention of various types with different sizes and weights such as unmanned aerial vehicles (UAV), micro unmanned aerial vehicles (μUAV), micro aerial vehicles (MAV), Nano aerial vehicles (NAV), Pico aerial vehicles (PAV), and smart dust (SD) [4][5].

Drones have been used in different places. It has been widely used in various applications of technology especially in the military fields, health care, monitoring of natural disasters, border control, and access to dangerous places that humans cannot reach, in addition to assistance in emergency and rescue situations and many other applications [6].

In the beginning, the drones were used independently to perform a specific task, as this was dangerous due to technical and other problems that could affect the drone, leading to the failure of the mission. Nowadays, there is a growing need to build networks of drones with diverse capabilities to perform many tasks. Hence the motivation to build such networks and use drones in building them for the benefits and capabilities they enjoy. To use these networks of drones in a variety of fields for both civil and military applications [7].

At the same time, there are many challenges facing drone networks. Whether it is network and resource management problems or others. Therefore, it is very important to choose the right infrastructure for building networks of drones. Through research, reading, and survey we find that software-defined networks are well suited for building networks of unmanned aircraft and their applications. This is because of the capabilities and benefits that it has that positively affect the construction and management of those networks. The centralized control makes software-defined network (SDN) ideal for a drone network, so we have applied a SDN to provide steady and efficient communication in a drone network that has irregular links and changing network topology due to drone movements, this makes managing the resources of these networks difficult. Where networks allow SDN programmatic control of network resources and it facilitates the management and implementation of tasks [7][8].

The SDN is an innovative approach to design, implement, and manage networks that separate the network control (control plane) and the forwarding process (data plane) for a better user experience. SDN is a new technology that makes computer networks further programmable, this technology allows the user to manage the network easily by permitting the user to control the applications and operating system. The main different iation between SDN and traditional networking is that SDN removes the decision-making part from the routers and it provides, logically, a centralized control-plane that creates a network view for the control and management applications [9].

1.2 Related work

There are many relevant research directions that suggest systems and methods for cooperation between SDN networks and drone's networks. Where many algorithms have been adopted and frameworks based on features of SDN-drone's networks to deal with the different topics correlated with computation power, management, routing, security, energy, and so on, we are summarized some of these research as follow:

Zhang et al. in 2018 [10] developed a SDN architecture for UAV networks based on the SDN. At the ground control station is mounted an SDN controller. They showed that an SDN deployment can extend the battery life of the UAV due to an integrated load balance algorithm within the SDN controller, it is different from the proposed system by in the proposed system consist of collector, and controller build in ground station.

Zacarias et al. in,2018 [11] they address the problem of highly mobile networks composed of UAVs as data providers of a military surveillance system. The proposed approach to tackle the problem is based on a SDN approach aiming at providing the best routes to deliver the data. The results were promising and demonstrate that programmable networks can be successfully applied to heterogeneous networks, disruptive networks, and networks with opportunistic connections.

Mohannad Alharthi, et al. in 2019 [12] the proposed a drone-based network architecture enabled by SDN to provide dynamic and flexible networking capabilities, suitable for different types of drone applications and deployments, as they discussed associated challenges related to SDN in done networks. They described use cases that demonstrate the configurability and reusability benefits of the architecture.

Hussein et al. in 2020 [13] a network of drones was built by using software-defined networks, Where the researchers did simulation work has been conducted to compare and investigate four SDN controllers (Pox, Ryu, Floodlight, and OpenDaylight) in order to see which one is suitable to be used and Mininet-Wifi has been selected as the simulation tool to do the experiments. The results obtained reveal that the Ryu controller is the best selection in terms of latency and packet loss.

Hossam S. Hassanein et al. in 2020 [14] they introduced a controller placement scheme for drone-based SDN networks. In such a dynamic and mobile network, maintaining SDN controller connectivity becomes a challenge. Address this challenge by implementing a dynamic scheme for controller placement that deploys a minimum number of drones that operate as SDN controllers and adjust their locations dynamically, the results show that the dynamic scheme minimizes the relocation distance of controllers, leading to minimizing the time of relocation and preserving the energy of controllers.

Kumar, A., Krishnamurthi et al. in 2020 [15] A scheme based on the use of the minimum required number of drone was used depending on the centralized SDN controller. Where the proposed system improved the ability to store the current communication records in the network and the performance was measured as well reduces overhead and increase the coverage area of the drones-SDN network.

Bhattacharjya, K., & De, D in 2021 [16] A system has been proposed based on edge-drone-of four-layer software-defined smart internet of underwater things (EdgeIoUT). As one of the models used to connect networks SDN with networks of drones. The results proved that the proposed system reduced energy consumption and increased packet delivery, as well as dealing with network load. It was adopted during the simulation of this network On the QualNet 7.1 simulator.

Sabitri Poudel and Sangman Moh. in 2021 [17] they propose a hybrid path planning (HPP) algorithm for efficient data collection by assuring the shortest collision-free path for UAVs in emergency environments. In the proposed HPP scheme, the probabilistic roadmap (PRM) algorithm is used to design the shortest trajectory map and the optimized artificial bee colony (ABC) algorithm to improve different path constraints in a three-dimensional environment. The simulation results show that the proposed HPP outperforms the PRM and conventional ABC schemes significantly in terms of flight time, energy consumption, convergence time, and flight path.

1.3 problem statement

There are many challenges and problems when using drones, whether the use as a single or in the form of a network of drones, and they can be summarized as follows:

1- Through field surveys and sites preview of institutions that use drones, the most important of which are security institutions such as the air force and army aviation of the ministry of defense, also the federal police and border guards affiliated with the ministry of Interior in Iraq, we have observed the drone operates as a single which makes it easy to destroy and steal, which leads to losing it and losing the information it carries, and therefore the mission fails.

2- Drone networks face many challenges and problems due to the huge amount of data generated by network nodes. We worked on the challenges of resource management and power-consuming and finding appropriate solutions to improve network performance.

1.4 Aims of the thesis

The aims of our work can be explained as the following:

1- Designing a network of drones that act as a swarm of UAVs. In order to solve the problems that face the drone when it operates alone. To use this network in multiple fields and applications where swarm can perform critical and risky tasks.

2- Building the network based on SDN technology. And taking advantage of the benefits and properties of this technology to solve the challenges of resource management and power-consuming which is considered problems that face drones network to improve network performance.

1.5 Thesis Contribution

The contributions of the work can be summarized by the following points:

1- Adding the collector with special specifications as it works in the form of a channel to connect the network nodes with the SDN controller, which is located in the ground station, where the collector drone performs simple control tasks as well as transmitting commands and data from the controller to the network nodes and vice versa, Moreover, it has other benefits in improving network performance.

2- Building a protocol called (Swap Collector) that does synchronize between the collectors of the network when the network contains more than one collector. In order to solve the problems of failure, energy, and other problems that could affect a particular collector drone and thus lead to the suspension of the nodes associated with that collector drone, this protocol transfers the tasks to another collector drone that has been pre-synchronized between them to ensure the network continues to operate.

1.6 Thesis Structure

The thesis is structured into five chapters:

Chapter Two presents the theoretical part of our work, which includes a general view of drones and SDN. Besides, it highlights more details about the classification of drones and communication and technologies for drone's networks. The chapter also explains the SDN for building and managing unmanned aerial vehicles networks.

Chapter Three introduces the proposed system drones network based on SDN. Then, it explains network architecture. The chapter explains the steps of work and configurations network.

Chapter Four presents the implementing of the proposed system in a simulation environment. at the same time shows the cases study that has been applied also presents the results for each of them. At the end of the chapter, discussed the results and compared the system.

Chapter Five presents the conclusions and suggestion future works.

Chapter Two

Background and theoretical part

2.1 Overview

This chapter presents the theoretical part and background of this thesis by explaining the drones and their network. Also explains the classification of drones and their most important uses. At the same time, it explains communications technologies for drone's networks.

Furthermore, it introduces the implementation of a Software-Defined Network (SDN) for building and managing drone's networks, and it highlights SDN architecture.

In addition, it introduces the simulation environment that is used in the present thesis to measure some parameters and performance of the network.

2.2 Drone definition and history

There are many different definitions of drones. Where they are defined in different methods and ways according to the opinion of researchers and manufacturers. Some researchers defined drones as an airplane that does not require a pilot to control its movements, where it can be controlled either remotely or by itself [17]. Also can be defined the UAVs are flying platforms, often known as drones, that include characteristics such as mobility, adaptable attitude, and flexibility [18].

Significant development of drones started in the early 1900s and originally focused on providing practice targets for training military personnel. The earliest attempt at a powered UAV was in 1916 By A. M. Low the monoplane was the one that flew under control on 21 March 1917 using his radio system. Other British developments followed during and after World War I leading to the fleet of over 400 de Havilland 82 Queen Bee aerial targets that went into service in 1935. [19]

The radioplane Company in1940 started and more models emerged during World War II – used both to train antiaircraft gunners and to fly attack missions. After World War II the development continued in vehicles such as the American JB-4 (using television/radio-command guidance) of 1951, while companies like Beechcraft offered their model 1001 for the U.S. Navy in 1955. [20]

During the War of Attrition (1967–1970) the first tactical UAVs installed with reconnaissance cameras were first tested by the Israeli intelligence, successfully bringing photos from across the Suez Canal. [21]

In 1973, the U.S. military officially confirmed that they had been using UAVs in Southeast Asia (Vietnam) [22].

With the maturing and miniaturization of applicable technologies in the 1980s and 1990s, interest in UAVs grew within the higher echelons of the U.S. military. Many of these UAVs saw service in the 1991 Gulf War. CAPECON was a European Union project to develop UAVs, running from 1 May 2002 to 31 December 2005 [23].

By 2013 at least 50 countries used UAVs. China, Iran, Israel, Pakistan, Turkey, and others designed and built their own varieties. The use of drones has continued to increase.

Nowadays, there is a growing need for flying drones with diverse capabilities for both civilian and military applications. There is also a significant interest in the development of novel drones which can autonomously fly in different environments and locations and can perform various missions [24]. Besides, some advantages of drones: [25]

1. Drones can perform longer and more hazardous missions than manned vehicles.

2. Maintenance costs are lower and personnel safety is far greater since no crew is onboard.

3. The low weight and compact dimensions of Drones give them enhanced maneuverability and deploy ability in shallow waters (riverine and coastal areas) where larger craft cannot operate effectively.

4. Drones also have greater potential payload capacity and are able to perform deeper water depth monitoring and sampling compared to other aircraft and spacecraft.

2.3 Classification of drones

Drones often vary widely in their configurations depending on the platform and mission. There are different classifications for drones based on different parameters, some of them will be explained:

- Some researchers described a variety of platforms. They identified advantages of each as relevant to the demands of users in the scientific research sector. They classified the drones' platforms for civil scientific and military uses based on characteristics, such as size, flight endurance, and capabilities. In their drones' classifications, they classified them as MAVs (micro or miniature aerial vehicles), NAVs (Nano aerial vehicles), VTOL (vertical take-Off & landing), LASE (low altitude, short-endurance), LASE Close, LALE (low altitude, long endurance), MALE (medium altitude, long endurance), and HALE (high altitude, long endurance) [26].
- At military drones, Brooke-Holland classified drones into three classes. And class I subdivided into four categories (a, b, c, and d). The categorization process is initially based on the minimum take-off weight combined with how the drones are intended to be used and where they are expected to be operated. Table 2.1 shown this classification [27].

Table 2.1: Military drone's categorization based on their weight

Class	Type	Weight range
Class I(a)	Nano drones	W≤200 g
Class I(b)	Micro drones	200 g < W≤2 kg
Class I(c)	Mini drones	2 kg < W≤20 kg
Class I(d)	Small drones	20 kg < W≤150 kg
Class II	Tactical drones	150 kg < W≤600 kg
Class III	MALE/HALE/Strike drones	W > 600 kg

In addition, classified drones on the basis of weight, range and endurance, wing loading, maximum altitude, and engine type. Also classified drones as super-heavy with different weights in kg. This classification is shown in Table 2.2 [28].

Table 2.2: Drones' categorization based on their weight

Naming	Weight range
Super heavy	W> 2000 kg
Heavy	200 kg <W≤2000 kg
Medium	50 kg <W≤200 kg
Light	5 kg <W≤50 kg
Micro	W≤5 kg

Besides, as others in [29] have arranged drones based on their weight and range as follows: micro and mini UAV close range, lightweight UAVs small range, lightweight UAVs medium-range, average UAVs, medium-heavy drones, heavy medium-range UAVs, heavy drone large endurance, and unmanned combat aircraft. In Table 2.3, the presented drones' classification which was mentioned.

Table 2.3: Drones' categorization based on their weight and flight range

Designation	Weight range	Flight range
Micro and mini UAVs close range	W≤5 kg	25 km≤R≤40 km
Lightweight UAVs small range	5 kg < W≤50 kg	10 km≤R≤70 km
Lightweight UAVs medium range	50 kg < W≤100 kg	70 km≤R≤250 km
Average UAVs	100 kg < W≤300 kg	150 km≤R≤1000 km
Medium heavy UAVs	300 kg < W≤500 kg	70 km≤R≤300 km
Heavy medium range UAVs	500 kg≤W	70 km≤R≤300 km
Heavy UAVs large endurance	1500 kg≤W	R≤1500 km
Unmanned combat aircraft	500 kg < W	R≤1500 km

Nowadays different types of drones evolved from the advancement in miniaturization of electronic components, such as sensors, microprocessors, batteries, and navigation systems. A wide variety of drones were used for military and civilian purposes. Drones range in size from vast fixed-wing UAV to smart dust (SD) which consists of many tiny micro-electro-mechanical systems including sensors or robots. In Figure 2.1, the spectrum of different types of drones is presented.

As shown in Figure 2.1, there is a spread spectrum of drones from UAV class with a maximum wingspan of 61 m and weight of 15,000 kg to smart dust (SD) with a minimum size of 1 mm and weight of 0.005 g. Between UAV and SD at both ends of the defined spectrum, there are various types of drones, which are called micro drones, such as micro unmanned aerial vehicle (μUAV), micro aerial vehicle (MAV), Nano aerial vehicle (NAV), and Pico aerial vehicle (PAV). Also in the figure 2.2 shows pictures of some types of drones that were mentioned [30] [31].

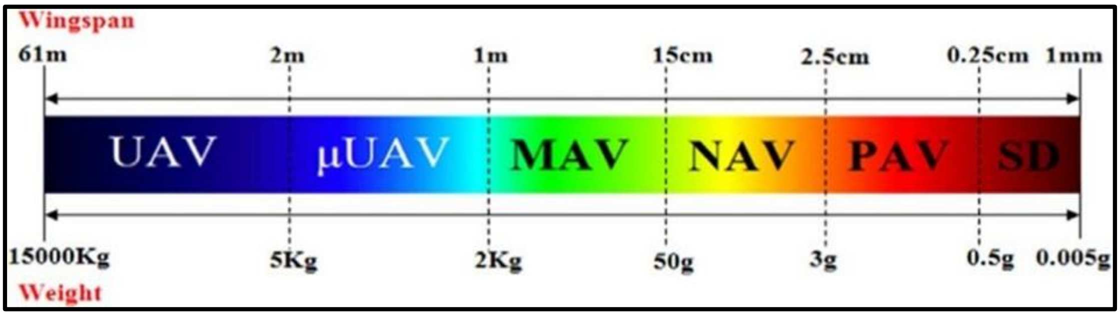


Figure 2.1 Spectrum of drones from UAV to SD [30].

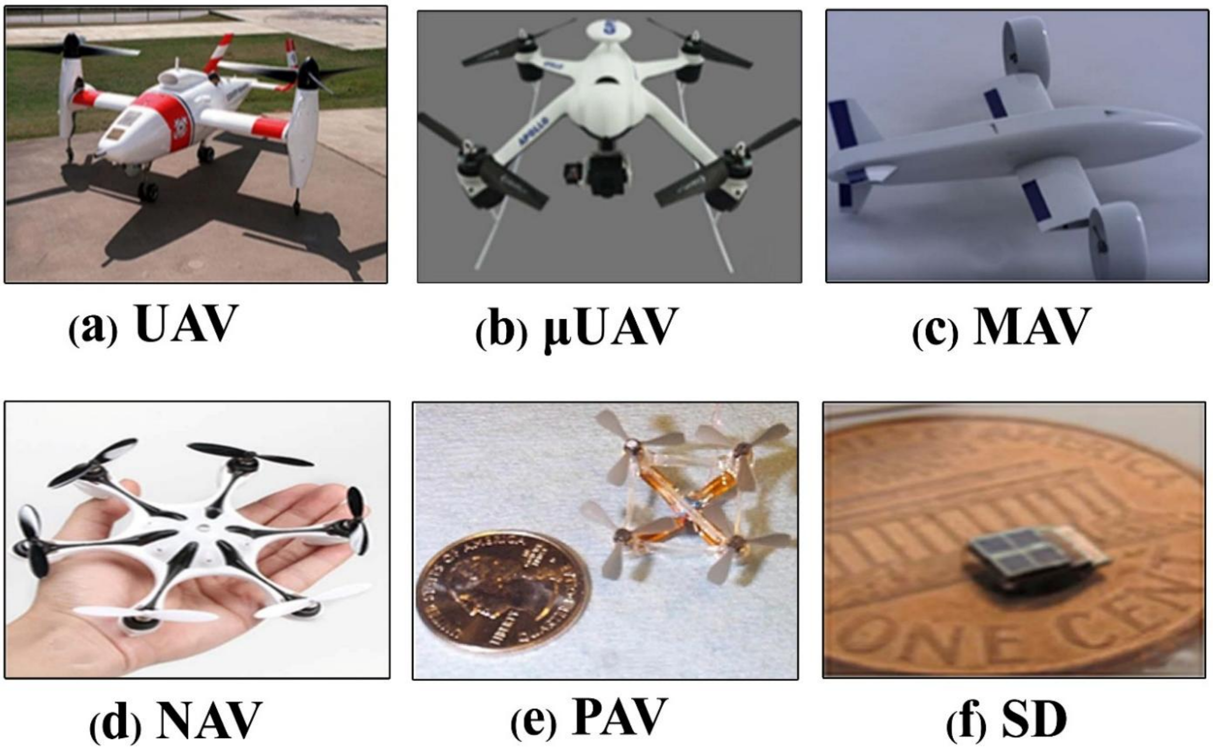


Figure 2.2 Pictures for some type of drones [31]

A specific type of drone is selected according to the mission or desired purpose. In the current thesis, the (μUAV) drones was chosen for their multiple characteristics and uses that suit our purposes.

A μUAV or small UAV (SUAV) is an unmanned aerial vehicle small enough to be man-portable. It is usually launched by hand and does not need a runway for take-off. And it is larger than micro aerial vehicles (MAVs), but can be carried by any person, and smaller than UAVs that cannot be carried and launched by hand [32].

2.4 Applications of Drones

Although the reason for the emergence of drones, in the beginning, was for the purposes of wars, as they were used in military applications. But due to the development of technology on the one hand and the development of the drone industry, on the other hand, drones have entered many civil, commercial, and science applications in addition to their military applications [33].

At present time the applications of drones cover a wide range of civil and military applications. Where drones can perform missions in very challenging environments. The applications of drones can be categorized in different ways. It can be based on the type of missions like military, civil, or others. In Figure 2.3 a flowchart of different types of drone applications are shown. As shown in Figure 2.3, drones have a variety of applications in our daily life. Drones can have more applications in the future according to their types. These drones can provide a rapid overview of the target area without any danger [34].

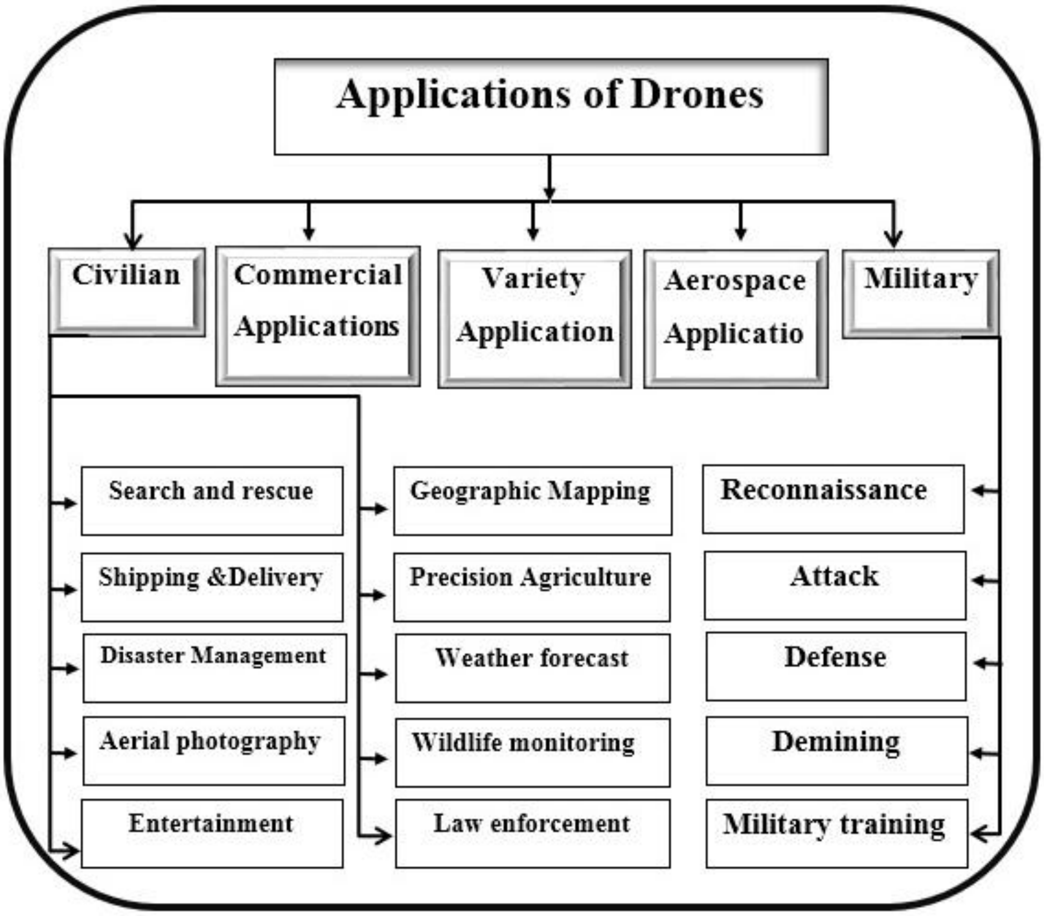


Figure 2.3 Different Types Of Drone Applications[33].

2.4.1 Drone applications in Aerospace

One of the environments in which drones can be used is space and the exploration of other planets, because of the advantages of drones compared to other robots, there is a tendency to design and fabricate some drones that can fly and perform missions in space environments [35].

2.4.2 Drone applications in Commercial

Commercial usage of drones is gaining steady momentum and has become the talk of the hour, as multiple industries are working with drones as part of their daily regular business functions. The commercial drone industry is still young, but it has begun to see some consolidation and major investments from industrial conglomerates, chip companies, IT consulting firms, and major defense contractors [36].

2.4.3 Military Applications

Drones are used by a broad range of military forces in the world, the development of drones' systems led to the possibility that the armed forces could perform military operations in a more efficient and less risky manner than was the case when the aircraft was piloted by people [37].

UAV systems are now bringing numerous capabilities and tactical air support to the armed forces, providing more capabilities and new fire capabilities. They can be used in a conventional operation as in the wars or can be used in an unconventional war, such as in the case of counter-insurgency operations [38].

2.4.4 Civilian Applications

Increased use of UAVs for military operations has unlocked new markets beyond military requirements for various civil applications. UAVs can be used in many civilian applications due to their ease of deployment, low maintenance costs, high mobility, and ability to fly, as showed in Figure 2.4 [39].

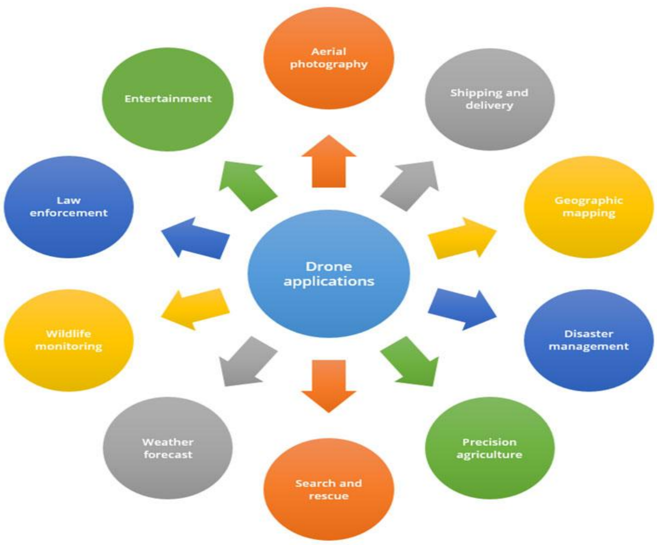


Figure 2.4 Drone Civilian Applications

2.5 Drone Energy Resources

Engine-powered drones are usually provided with various fossil fuel sources, such as gasoline, methane, and hydrogen. In small drones, the required power is provided by the battery. Over 90% of these drones used lithium power (Li-PO) batteries. For micro drones, lithium batteries are the best choice of power due to their low weight. Fossil fuels can produce more energy than batteries, but the available internal combustion engines for use in these drones have extremely low efficiency, and the fuel usage may cause stability problems for micro aerial vehicles. However, the micro fuel cell is under development and this technology is yet to be used in micro drones [40].

At present, small Li-Po batteries are the most widely used power sources. The interest to use micro drones for various missions is increased and flight time depends on power consumption It can also solar panels and piezoelectric energy harvesters can be used as renewable energy sources or to operate extra sensors and cameras. [40]

Nowadays, mounting solar panels on drones is considered a common method to increase energy, and usually, the battery is used as a backup when the solar cells cannot produce enough power flying in or under clouds or in the dark. In other words, a hybrid source which is a combination of solar cells and battery is usually used for powering drones. Also, the solar cells must have low weight, must be flexible, and have a high efficiency. [41]

As well as can use laser light from a common power source, such as a portable generator or the electrical grid as a power source and battery recharge for drones. This laser beam is directed to a photovoltaic receiver which is installed under the drone. One of the main advantages of wireless power systems is that the energy source is on the ground where power is easier and cheaper to generate and laser systems do not need to turn off at night and can continuously charge the battery.

Even though this system can solve the energy issues, it has some problems in the range of flight. For instance, this system cannot be applied for high altitude UAVs, but it can be a good choice for rotary wing micro aerial vehicles that have a flight range of less than 5 km. [41]

2.6 Network of Drones

Using one drone only for a specified mission can be risky because the drone may encounter some technical or other problems, but various missions can be performed with more efficiency by applying multiple drones. Therefore, nowadays due to advances in communication, intelligent software, and processing power, a network of drones is considered as one of the important topics in drones' studies [42].

A network of drones has an advantage, if one drone of the swarm is lost in flight, the rest of the drones can carry out the mission. The network of drones has become very popular in the last few years. It is the objective of several research groups from different organizations to make drones fly as a group and act autonomously without the interference of humans [42].

Nowadays, there are many efforts to develop drone's networks technology. As an example, the Naval Surface Warfare Center has offered a new approach for formation flight. In their design, they considered the new formation of the drones when a few of them malfunction or have other problems, such as engine failure. In this situation, the other drones become aware of this problem and they find a new formation that allows the rest of the drones to collect the data which the damaged drone was supposed to collect. Researchers developed a group of drone's software for use in disaster situations, where they applied it on micro drones. They developed software to make the decision as to which flight path is better than another in disaster situations [43].

2.7 Communication of Drones networks

Initially, drone units were used independently; nowadays, however, multiple synchronized drones often perform critical operations together.

Drone communication plays a critical role. Thus, it is important to understand various aspects of UAV communication. On the other hand, different types of wireless channels and network protocols are employed in drone communications. Therefore, the communication mechanism which is used for the UAV network depends on the application. For example, in outdoor communication, it has been observed that a simple line of sight point-to-point communication link between the drone and the device can be utilized without any break in signal transmission. Another example is surveillance, where drones effectively communicate through satellite communication links. [44]

A diagram summarizing the communication technologies of drones, their linkage with recent technological advancements, and their combined applications are laid out in Figure 2.5.

The idea is to represent how each part from the left, middle, and right portions can be connected together. For example, if communication is established between a drone and an ambulance through a sophisticated vehicular communication system, an artificial intelligence algorithm running offline on a drone or online on a cloud can monitor the paths and determine the best route to provide emergency aid.

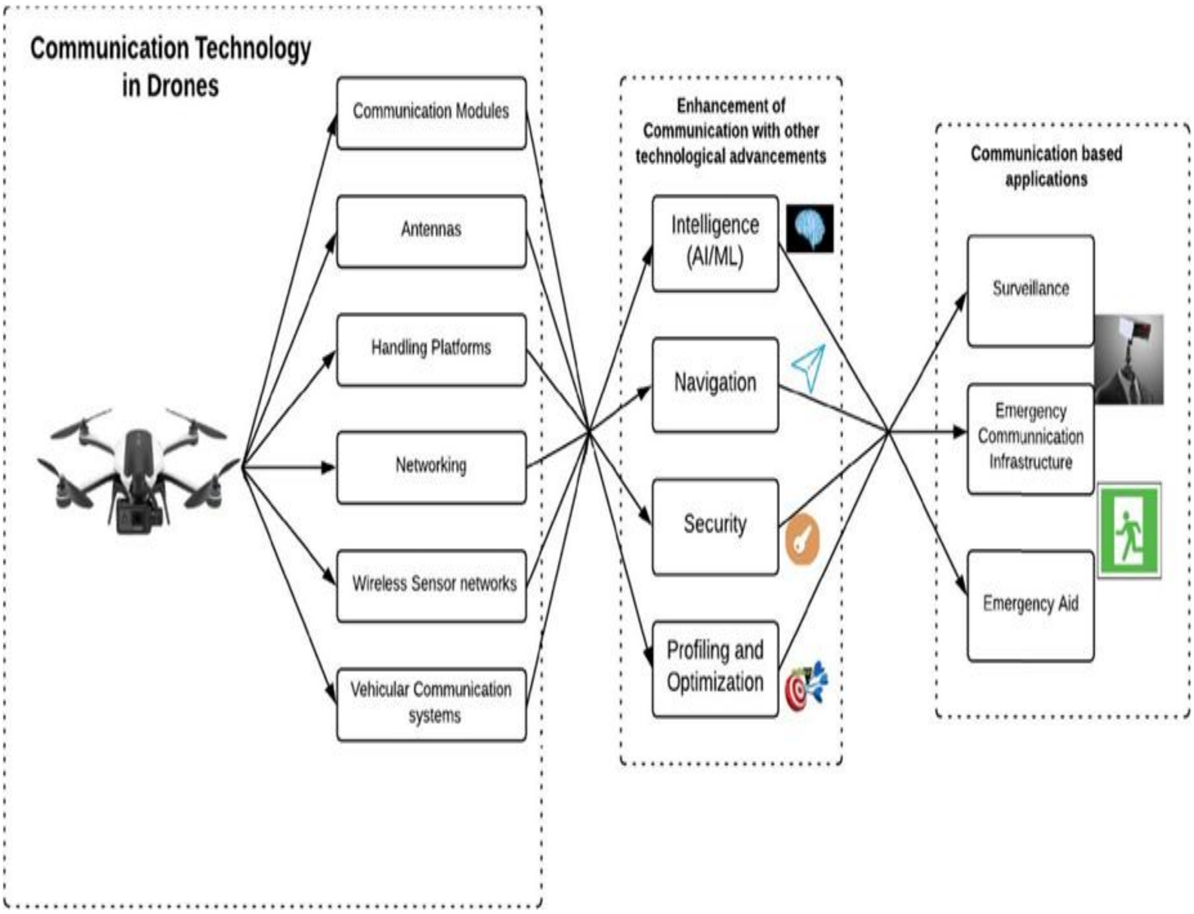


Figure 2.5: Communication technology's potential with Drones.

The left portion of the diagram presents some key attributes of the communication technology of drones. The figure also shows the association with the four major disciplines in the middle portion [45].

A chose worldwide interoperability for microwave access network (WiMAX) as a suitable technology for studying wireless communication technologies such as ZigBee, WiFi, XBee, and WiMAX, which are based on SHERPA network standard criteria [46].

Besides, used an Adaptive Forward Area Based Routing-algorithm (AFAR) for drones while using Geographic Information Systems (GIS) to study flooding, which is well suited for drones when correctly modified. Evaluation with Destination- Sequenced Distance-Vector (DSDV) routing protocol has confirmed a better packet delivery ratio for AFAR-D [47]. In another work at developing a networking system RMICN (Router- movable Information-centric Networking) particularly for facilitating communication between disjointed networks. It used the movement of physical control of flying routers and relay nodes to improve flexibility and efficiency [47]

A path planning algorithm called Improved Ant Colony Optimization (IACO) was used for a group of mobile robots [45].

In addition, focused on another aspect of resource allocation, identifying the best frequency band for individual drones so as to enable the maximum number of drones to use the using main communication band while simultaneously avoiding interference. has been improved the maximum ratio of drones using the main band relative to the total number of drones by increasing the size of the primary exclusive region. high interference was observed at the radio control unit only in the 2.4 GHz wireless band. Drones networks work has recently started to gain more interest for general applications. Table 2.4 shows up compared and evaluated technologically for existing algorithms and approaches for drone networks [48].

Table 2.4 Compared and evaluated technologically for existing algorithms and approaches for drone networks [48]

Protocols	Selected	Selection criteria	Advantage over remainder
WiMax, ZigBee, WiFi, XBee	WiMax	SHERPA network standard	Broader coverage and lower data loss rate in hostile areas. Consider other parameters too.
AFAR-D, DSDV	AFAR-D	Packet routing	Better packet delivery ratio.
RMICN	RMICN	Communication Between disjoint networks	Improved flexibility and efficiency.
IACO	IACO	Path planning	Better network between regions.

2.8 Drones networks challenges

There are many challenges and considerations when building a network of drones that must be taken into account, we present some of them below:

2.8.1 Mobility

Drones networks are characterized by highly mobile nodes and diverse mobility models. The high mobility and speed of nodes cause changes in network topology and network partitioning. Nodes in UAVs networks are characterized by a high degree of mobility which results in several challenging communication design problems. The degree of mobility of UAVs is fully dependent on the application. For example, an earthquake struck, the UAVs would fly over the area of operation and must provide communication over links which would be slow or dynamic [49].

2.8.2 Adaptation

Many drones network parameters can change during the missions. Drones networks must adapt to changes and they should be capable enough to withstand the dynamic changes. The most prominent changes in such networks are the drone locations, the distance between drones, and the routes. Moreover, drone failures are frequent in the drone's networks which generates the need for drone injections [49].

2.8.3 Reliability

The drone's networks while operating may be affected by various network attacks which can degrade the network performance. UAV network model should be fault-tolerant, robust, and reliable. Thus, reliability depends on various parameters related to the mission task[49].

2.8.4 Scalability

To reduce the cost of re-planning and re-organizing, the drone's networks should allow adding new drones, therefore, it must be highly scalable. In fact, the scalability in the drone network is related to the nodes, and also to the resources. Performance and energy management are the most prominent parameters to evaluate the drone networks. The multi-hop communication in the drone link chain is used to extend the operation area. Besides, the obstacles in the operation area can influence the communication coverage of the infrastructure. The obstacle can be mountains, constructions, walls, or buildings which may stop the radio signals between the ground base station and drone. Therefore, drone's networks must extend their scalability by hiding the obstacles and by adding more relay nodes [49].

2.8.5 Latency

Drone's networks must reduce latency and hind unpredicted delays. The latency constraint depends on the application. For example, in military monitoring, the mission over links must be done with minimizing delays. Also, to avoid collisions in multi drones networks it is required to decrease latency [49].

2.8.6 Bandwidth

The bandwidth requirement depends on the application. Applications that require a high transfer rate must have high bandwidth. The selection of the appropriate network bandwidth is based on the tradeoff between energy efficiency and bandwidth efficiency. For example, the applications using drones to collect data from distributed data sources in different areas and relay the collected data to a ground base station require high bandwidth. The application using advanced sensor technology can collect data with very high resolution, which requires higher bandwidth [49].

2.8.7 Energy and Power-consuming

Drones network power is based on the energy source of the drone. However, the small drones may typically have not enough power to fly and communicate during missions and they haven't the capability of refueling. It is required to design efficient configurations to control and decrease consumed power. Power consumption configuration influences the network lifetime because when the drone's power is drained, there are no transmitted signals and the links become intermittent [50].

2.9 Software-Defined Network

Software-Defined Networking is a new adventure in the networking domain which is different from traditional networking models. In this technology, SDN Controllers performs the control decision task in either centralized or distributed mode. It has been considered as the biggest hopeful outcome for the upcoming Internet. SDN results in a more efficient and innovative design and delivers better performance with higher flexibility without the use of monopoly devices [9].

This technology allows the user to manage the network easily by permitting the user to control the applications and operating system. SDN not only introduces new ways of interaction within network devices but also gives more flexibility for the existing and future networking designs and operations [56].

The main differentiation between SDN and traditional networking is that SDN removes the decision-making part from the routers and it provides, logically, a centralized control-plane that creates a network view for the control and management applications [56].

According to the definition of the term “Software Defined Networking” given by the Open Networking Foundation (ONF) organization, it is: “A network architecture where the network control plane is decoupled from the forwarding plane, and the control plane controls several devices. The ONF is a non-profit organization that has developed OpenFlow standard which is the first communication interface for the communication between the control plane and the data plane [57].

Based on the definition given by the ONF the key idea of SDN architecture is the removal of the control element from the hardware component and the centralization of the control element in a software component known as SDN controller [57]. The SDN controller is the control intelligence in SDN, it is a software control program. There may be more than one SDN controller if the network is large-scale or a wide-area region network. The control layer globally regulates the network states via network policies in either a centralized or distributed manner [58].

2.10 Software Defined Drone Network

Software-Defined Network (SDN) has better controllability and visibility of network components which enables better management by using the controller. In applications of drones, wireless networks must be configured efficiently for seamless integration and disintegration of drones, such as changing protocols and creating new paths. Based on the SDN architecture, drones can do as SDN switches on the data plane for gathering context information in a distributed way, while the ground stations are controllers gathering data and making control decisions on network functions and resource allocation. Helped by SDN, network reconfiguration and resource allocation among a network of drones can be conducted in a more flexible way. [51]

The centralized point of view about the whole network through using a controller enhances the functionality and performance of network devices. As a result of enabling the fastest possible protection in the incident of a failure, the highest resiliency, and the ability to place new services into a network in one command via using application programming interfaces (APIs). SDN could facilitate flexible deployment and management of novel services and help reduce cost, increase security, and availability in networks [52].

The centralized control makes SDN ideal for a drone's network because drones networks are usually of small sizes. Moreover, all the nodes in a drone's network cooperate towards a common goal; therefore, every node (drone) is willing to share control information with the SDN controller. In SDNs, the controller collects the network statistics information from switches, then installs flows on switches, and sends administrative policies to switches. The controller also requires knowledge about the latest network topology. Therefore, connectivity between the SDN controller and the drones is tremendously important. A key feature of a deployment method is the placing of the SDN controller [53].

2.11 Advantages SDN for Drones Network

Compared to traditional network devices, SDN forwarding devices (switches) are simpler and cheaper via the centralization of the network controller. Another advantage is that the network administration and setup are simpler.

In the present network architecture compared with SDN, SDN can be reconfigured faster to respond to the new business requirements. Through SDN, the network performance is improved globally. Besides that, any new application, protocols, and policies can be easily implemented through an application running on the controller which controls the forwarding devices via well-defined APIs, such as the OpenFlow protocol [54]. Below are some highlights of the specific benefits of SDN:

- **Content Delivery**: Controlling data traffic is one of the primary advantages of SDN. The ability to direct and automate data traffic makes implementing Quality of Services (QoS) for data transmissions much easier [55].

- **Lessen Capital Expenditure:** By implementing SDN, businesses can easily optimize existing network devices. Existing hardware can be repurposed to follow the instructions of an SDN controller, and more cost-efficient hardware can be deployed with greater effect [55].

- **Centralization:** SDN offers a centralized view of drones networks, making it easier to streamline network management and provisioning. SDNs can speed service delivery and provide more agility for both virtual and physical network provisioning, all from a central location [55].

2.12 Architecture of Software-Defined Network

SDN architecture consists of 3 layers: infrastructure layer, control layer, and application layer as shown Figure 2.6. The infrastructure layer or data plane is responsible for forwarding the packets by means of simple forwarders.

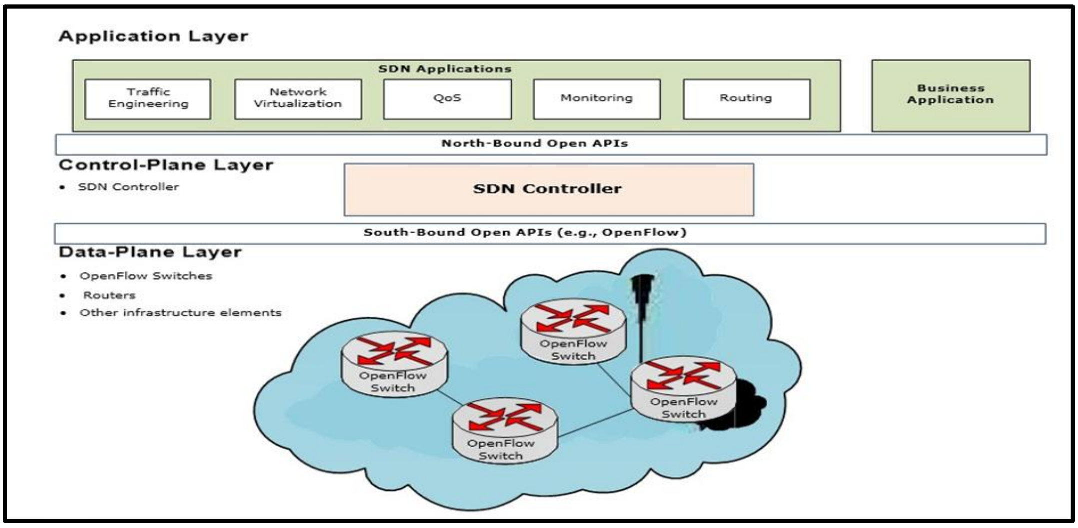


Figure 2.6 Software Defined Network Architecture [59]

The Control layer contains the controller to manage the Infrastructure layer. In the application layer, the business applications can interact with network services and capabilities. There is also a need for southbound and northbound interfaces to enable the controller to communicate with the two other layers [59].

2.12.1 Infrastructure Layer

The infrastructure layer is the SDN switch. Switches in software-defined networks are basic forwarding elements that communicate with controllers via an open interface such as OpenFlow. An OF switch consists of at least three main parts: flow table, secure channel, and OpenFlow protocol. Flow table is used to lookup packets and also do forwarding. A secure channel is usually a TLS or SSL channel between switch and controller. OpenFlow protocol is for communicating with the switches and managing them [60].

2.12.2 Control Layer

The control plane acts as an intermediary layer between applications and the data plane. The control plane in SDN is called a controller, it communicates with the application via the northbound interface and with the switches via the southbound interface. Therefore, in the control plane, it is important to design interfaces and the controller itself in an efficient way. There are many controllers that have been written in different programming languages, Table 2.5 displays the most famous controllers. This table was filled by collecting the latest information from various sources [61] - [67].

Controllers can be deployed in a centralized or distributed manner. One of the most obvious advantages of using a centralized controller is that management and retrieving the information would be applied from one logical point (controller) resulting uniform network.

A centralized controller like each centralized model has the disadvantages of a single point of failure, terminating no availability and scalability. The network could have more than one controller, so each controller is responsible to control a group of network switches, which may interfere with each other, thus one controller is chosen to be the main controller and the others would be backups.

2.12.3 Application Layer

The application layer is consisting of one or more applications that can be applied in the SDN network; it is configured and developed by using various SDN controllers. Each one of these applications has exclusive control on a set of resources in one or more SDN controllers. On the other hand, the SDN applications that are found in the application layer can communicate with the controller via Northbound API, also the controller provides relevant information about network elements to the SDN applications [60].

Table 2.5 Some of SDN controller [60].

Controller	Language	OF version	Description
NOX	Python, C++	1.0, 1.3	Asynchronous, event-based programming model, component based framework. NOXMT is multithreaded with improving throughput and response time.
POX	Python (2.7)	1.0	Component based framework, targets Linux, Mac OS, and Window.
Beacon	Java	1.0.1	Event based and threaded Cross-platform, Dynamic, and Rapid Development.
Maestro	Java	1.0	Modular network control applications, multi-thread.
Floodlight	Java	1.0	Based on Beacon, core architecture is

			modular, open source agent (Indigo).
Floodlightplus	Java	1.3	New version of floodlight for supporting OF 1.3.
Ryu	Python	1.0, 1.2, 1.3, 1.4	Component based, supporting components development in other languages, event management and reusable NETCONF library, sFlow/Netflow library.
OpenDaylight	Java	1.0 , 1.3	Modular, pluggable, and flexible controller platform, supporting multiple southbound protocols.

In the current thesis, the Ryu controller has been chosen because it is widely used, provides well documents, and defines API for creating various SDN applications. Simulation results of different types conducted in this work prove that the Ryu controller is the best selection.

2.12.4 OpenFlow Protocol

The OpenFlow protocol is the most common interface between the data-plane and control-plane in SDN.

In SDN, the controller manages the collection of switches for traffic control. The communication between the controller and the OpenFlow switch is through the OpenFlow protocol. Besides that, the controller also manages the switch through this protocol. The SDN South-Bound interface is provided by the OpenFlow Protocol.

In other words, the communication interface between the SDN controller (control-plane) and SDN switches (data-plane) is provided by this protocol. This protocol allows the SDN controller to configure and manage the SDN switches [68].

An OpenFlow Protocol specifies how traffic should flow through the network by allowing the controller to access and manipulate the flow tables (forwarding rules) of the SDN Switch, Figure 2.7 shows a model of the OF protocol. Each incoming packet is matched against a set of rules and the action list associated with the matching rule is executed [69].

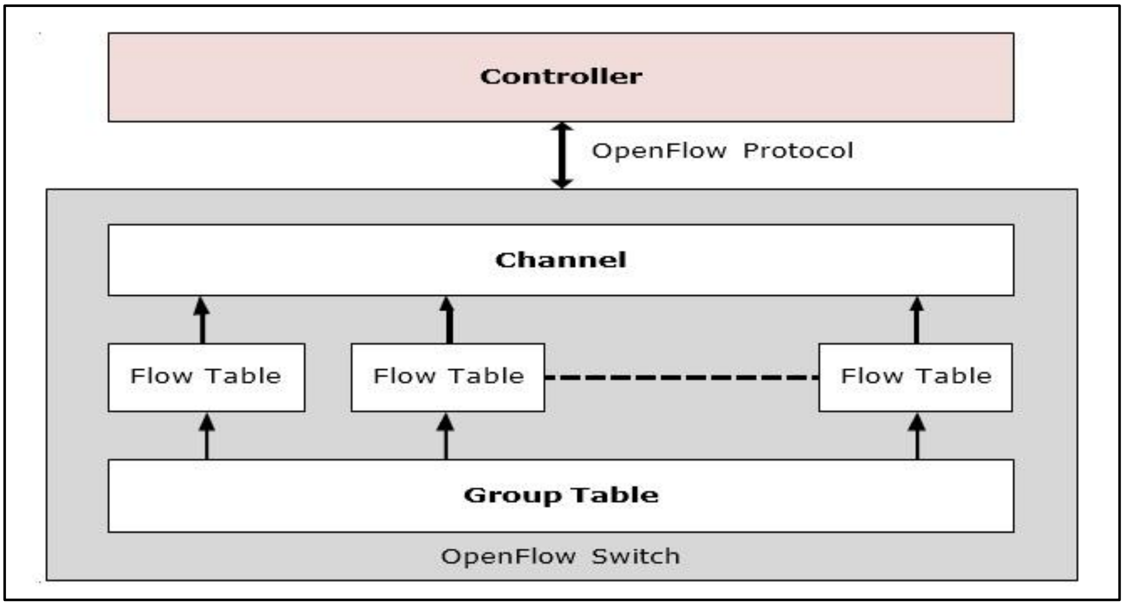


Figure 2.7 OpenFlow Model [69]

2.13 Evaluation Metrics

The proposed system based on the different evaluation metrics for comparison case studies explained as follow:

A- **Throughput(Kbps)** often characterize the amount of data that the network can transfer per unit of time [70].

B- **Battery lifetime(mW):** It is the time of power supply pro-vided by batteries before they drained, directly impacting the sensor nodes liberty [71].

C- **Power consumption (mW):** It is the energy consumption of each sensor node per unit of time [71].

D- **Packet Delivery Ratio (PDR)**: It is the ratio of successfully delivered packets among the transferred packets. Having the maximum number of packets delivered to the UAV is highly desirable to achieve better network performances [72].

E- **The delay time**: It is the time used to transmit packet from the sender to the receiver and it explains the delay time simulation parameter for entire packets. It is computed based on the following equation [72]:

$$d\_trans = L/R \quad \ldots. (2.1)\ [72]$$

Where d represents as delay time in seconds and L is the packet length in bits and R is the rate of transmitted data in bits per time unit.

2.14 Implementation and Simulation Tools

In addition to the real implementations of the Drones network, there are many simulations, programming languages, and frameworks that allow the possibility of applying this network and various research directions as in the simulations tools mentioned below:

F- MATLAB and Simulink

MATLAB and Simulink provide capabilities to speed up the development of UAV and autonomous flight applications. With MATLAB and Simulink, you can [73]:

- Model and analyze a UAV system architecture
- Design flight control algorithms and simulate with a UAV plant model while including environmental factors
- Develop perception and motion planning systems for autonomous flight using prebuilt algorithms, sensor models, and apps for computer vision, lidar and radar processing, and sensor fusion

- Evaluate UAV performance in a closed-loop 3D simulation environment

- Automatically generate production code to deploy to flight controllers and onboard compute boards

- Connect to and control UAV from MATLAB and Simulink

- Analyze UAV flight telemetry and payload data

G- Mininet-WiFi

Mininet-WiFi is employed to perform simulations on similar topology in MANIAC to evaluate whether the presented approach can satisfy the desired goals. Mininet-WiFi incorporates novel categories to provide the possible addition of the mentioned wireless mobile devices in a Mininet network framework. Moreover, measurements can be obtained through an actual traffic overhead and delay in a simulated approach, as well as, it used to investigate and compare Software-Defined Network Controllers for UAV Networks Management [74].

H- NS-3

It can simulate many technologies and embeds a variety of statistical models for channel gain, mobility, and traffic generation, and provides detailed modeling of physical layer operations. Additionally, NS-3 can efficiently interface with external systems, applications, and libraries [75].

I- OPNET

It is a commercial simulator providing a detailed simulation of wireless networks and supports a wide spectrum of protocols and technologies. It was used in different research directions, it developed a multi-UAVs communication network simulation platform [76].

J- FlyNetSim

It is based on C/C++ and Python. It is an Open Source Synchronized UAV Network Simulator based on NS-3 and Ardupilot FlyNetSim – bridging the two domains. The overall objective is to enable simulation and evaluation of UAV swarms operating within articulated multi-layered technological ecosystems, such as the Urban Internet of Things (IoT). To this aim, FlyNetSim interfaces two open-source tools, ArduPilot and NS-3, creating individual data paths between the devices operating in the system using a publish and subscribe-based middleware [77].

- **OMNeT++.**

It introduces an integrated coordination and management strategy for UAV networks, which includes formation coordination algorithms and an SDN-based UAV communication protocol. The network is composed of three different types of nodes: a controller node, a set of relay nodes, and a set of user nodes. Relay nodes aim to sustain communication links among user nodes for as long as possible. Hence, the controller node is in charge of finding and setting up the best location for the relay nodes through formation coordination algorithms as part of his coordination functionalities. simulations were also performed in the OMNeT++ simulator. Throughout video transmissions among users, relay nodes were imposed to failure, therefore the controller should be able to manage the network for retrieving those connections [78].

Aerial Vehicle Network Simulator (AVENS) implements co-simulation between an OMNeT++ simulation and the XPlane Flight Simulator, for modeling UAV (Unmanned Aerial Vehicle) communication. The purpose of AVENS is to offer a platform for mobile ad hoc networks analysis where UAVs are mobile nodes sharing the wireless medium for exchanging messages. The goal is to use a flight simulator for controlling the aerial vehicles and a network simulator for obtaining network measurements such as transmission rate, good put, RSSI (Received Signal Strength Indication), throughput, package loss, number of retransmission etc. [79].

In order to implement our work, we used the OMNeT++ simulation to implement a drone's network based on SDN.

We choose OMNET ++ because it's easy to use with Graphical User Interface (GUI) for the Windows operating system. This GUI provides different features of tracing, debugging, and execution:

1- It's recommended in the main development simulation stage since it allows to get a detailed picture of the simulation state at any point of execution timeline.

2- It is modular with different (Frameworks, Libraries, Models, etc.) which save time and effort for researchers to carry out research simulations like the real environments.

3- Following what happens inside the network.

4- The flexibility of learning where it depends on the C++ programming language.

5- OMNET++ graphical user interface based on network description topology of description language which traces what happens inside the network [80].

Chapter Three

The proposed System

3.1 Overview

This chapter showed the proposed drone network based on software defined networks system steps and main configuration, algorithms and network architecture. The proposed system showed The SDN controller which it is a key component in the network and it has a direct effect on network performance, especially it considers the main controller point on the entire environment. In addition, the network topology with the SDN layers showed with the drone nodes in data plane, controller in control plane and application results in application layer.

3.2 The Proposed Drones Network

The proposed system based on drones or as it known UAVs with Software Defined networking technology of SDN controller management process.

The goal of using drones in the proposed system is reducing the cost of missions and eliminating associated risks of sending human personnel to conduct risky or costly tasks.

In addition, the goal of using SDN in the proposed system is enhancing monitoring, network performance, decreasing network overhead in resources constraints like drone's sensor networks also it enhanced optimal decision intelligently in UAV network.

As mentioned, the network is managed by a ground management system that carries out the planning and deployment of drones, and the monitoring, management, and control of the network during the mission. Besides in some cases when a collector failure occurs, the task will be assigned to another collector to do its function, a pre-synchronization has been made between them.

However, the proposed system steps explained in the block diagram in Figure (3.1), from the first step of drone network sensors in the data plane to the application layer to build result statistics.

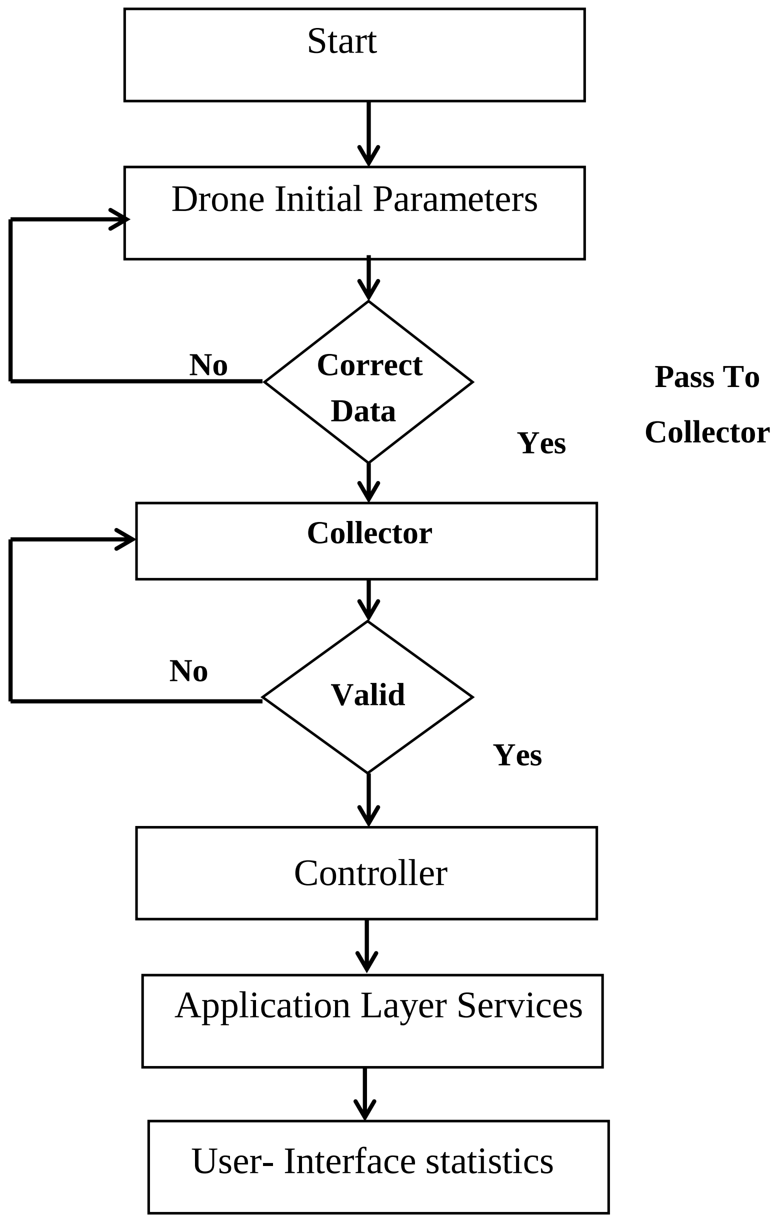


Figure 3.1: The block diagram of the proposed system steps.

3.3 The Network Architecture

The proposed network architecture can use in different drone applications. Drones comprise the nodes of a multi-layer wireless network. Drones are designated as either network drones or task drones. Network drones act as switches (Collector) in a typical SDN network forwarding traffic. Network drones are SDN-enabled and programmable via an API such as OpenFlow. SDN is utilized to enable programmability and configuration of network nodes and to manage the forwarding of traffic using multiple network interfaces installed on drones. Task drones perform the actual tasks related by the mission, such as sensing, monitoring, or providing wireless access to ground users.

The network is sufficiently flexible to enable deploying the network beyond the reach of the ground system. In such cases, SDN controllers and applications are deployed along with the network on controller drones. The management system hosts the main SDN controller of the network.

The architecture of the used network showed in the Figure (3.2), which it based on the SDN and drone architecture which it consists of:

- Data plane as drone's nodes for task drones which they perform the actual tasks related by the mission, such as sensing, monitoring, or providing wireless access to ground users (the proposed system contains on 6, 10, 20 drones in this layer).
- Collector to connect and manage data from the source nodes (the proposed system consists of two collectors).
- Ground station (SDN controller) which it responsible on data flow and data analysis with application layers to building system results.

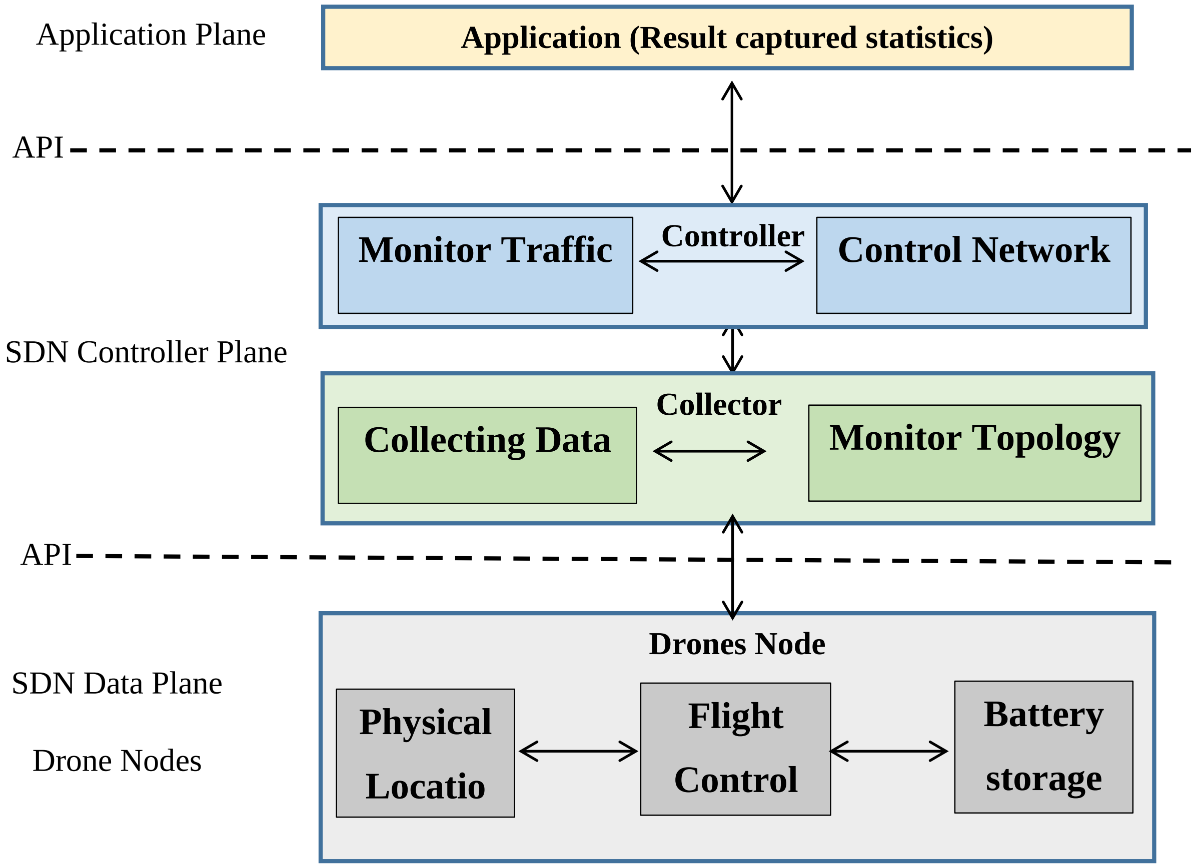


Figure 3.2: Architecture of Drone Network based on SDN.

The proposed SDN-Drone network architecture consist of:

3.3.1 Drones as the network node

Drones form the nodes of the multi-layer network. Each drone can be different in terms of its capabilities, in the proposed system it provides more wireless interfaces with OpenFlow support services, storage elements for log file recording, and virtualization to host task applications within SDN services. It provides sensing, monitoring, or providing wireless access to ground end users.

3.3.2 Collector Drones

Collector drones are flying, it is responsible of collecting data from sensors nearby and connected with, then it sends the collected data of drones to the Controller. Besides, it controls the performance of group drones by managing it in an efficient and effective way. The main advantages of Collector as follow; it helps to make the network more scalable, reduce routing, overhead and maximize the throughput.

3.3.3 Controller

SDN controllers that are deployed with the drone network to optimize and distribute the logically centralized SDN control functions. This is also beneficial when the network needs to be deployed to a remote location away from the management system, and where communication infrastructure is inaccessible to the mission.

SDN Control Component (SDNC): This component consists of the SDN controller to control the data plane of the drone network. The SDNC can be realized using extensible library SDN controller platform which it used as RYU controller system. It runs on virtualized drone computing re-sources. Such applications include any specialized programs that manages task specific equipment such as sensors and cameras. The network topology showed in Figure 3.2, which is can be based on 6, 10, or 20 nodes.

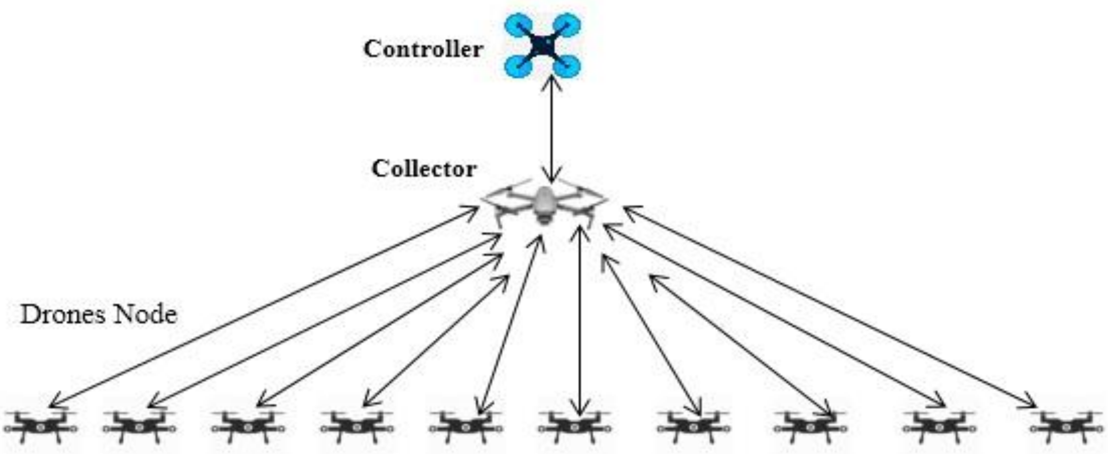


Figure 3.3: The proposed network Topology.

3.4 The Configurations of the proposed System

The proposed SDN-Drone system based on the two sections in the used environment as follow:

3.4.1 The Drones Node Configurations

The proposed configurations of drone's node consist of many sections to build the drones environment, they are summarized as: in the first calculate distance of nodes mobility, in the second Movement management: a grid smaller or equal simulated Dimensions would mean that every cell has every other cell as direct neighbor. Third section, Initializing the matrix which represents the used grid with copy empty network interface card, Fill the matrix rows., Fill the network interface card Grid matrix, Passing generated values. In the fourth section calculating the factor which maps the coordinate of a node to the grid cell building the coordination of the playground distance (X, Y, Z). as showed in algorithm (3.1).

Algorithm (3.1) : Coordinate Dimensions
Begin Reassign(U) 1: if there are unassigned nodes then 2: sol = CReloc() - for (int i = 0; i < gridDim.z; ++i) - for (int i = 0; i < gridDim.y; ++i) - for (int i = 0; i < gridDim.x; ++i) 3: else if sol is infeasible then 4: CPlace() 5: end if **End Algorithm**

3.4.2 Network Elements Configurations

This section explained the network elements configurations, in addition to the connection manager among network elements, and these configurations showed as follow: in the first, manage generic connection manager interface to debug switch, send directly to the node, maximum sending power in [mW], minimum signal attenuation threshold in [dBm], minimum path loss coefficient and minimum carrier frequency of the channel in [Hz].

In the second section, building module to control all connection of the central module, connection manager. The third section is SDN controller setting to debug controller, send directly to the node, and determining maximum sending power.

In the fourth section, making SDN collector setting with (ports, sockets, gates and connections), scheduling nodes, collecting capture messaged from drone nodes, and Passing values to the controller. Besides, the used SDN module algorithm explained in the algorithm 3.2.

Algorithm (3.2) : SDN module algorithm

Input: new drone assignments for U, unassigned drones

Output: gathered data from data plane

Begin

```
unassignedDrones  empty
for ui 2U do
if path loss for current assignment <Qm then
continue
end if
 nearbyCtls  empty
for j = 0 to Nd do
if pathloss for cj to drone new loc < Qm then
add cj to nearbyControllers
```

Algorithm (3.2) : SDN module algorithm
10. end if 11. end for 12. sort nearbyCtls by path loss to new drone location 13. while nearbyCtls not empty do 14. ctl pop(nearbyCtls) 15. if ctl:load +di rate 16. Scapacity then 17. assigndito ctl, continue 18. end if 19. end while 20. add to unassigned drone list 21. end for **End Algorithm**

In the fifth, channel Setting to request for packets transmission, defining the sensing mode as IEEE 802.11ac, which managed with time to listen on the channel. Besides, the packet NetwPkt features simulated as in the algorithm 3.3:

Algorithm (3.3) Pseud code of network layer packet NetwPkt

Begin
1. Network LayerPacket class (int sd, struct sockaddr_in* address) : msd(sd)
- char ip[25];
- inet_ntop(PF_INET, (struct in_addr*)&(address->sin_addr.s_addr),
- ip, sizeof(ip)-1);
- m_peerIP = ip;
- m_peerPort = ntohs(address->sin_port);
2. int IPConnector::resolveHostName(const char* hostname, struct in_addr* addr)
- struct addrinfo *res;
- int result = getaddrinfo (hostname, NULL, NULL, &res);
- if (result == 0) {
- memcpy(addr, &((struct sockaddr_in *) res->ai_addr)->sin_addr,
- sizeof(struct in_addr));
- freeaddrinfo(res);
return result;
End Algorithm

The base Physical Layer algorithm steps showed in Algorithm 3.4, as:

Algorithm (3.4) Pseudocode of Base Physical Layer module	
Input	**Configure devices with:** - debug switch for core framework - enable/disable tracking of statistics - defines the length of the phy header (/preamble)
Output	Physical signals to pass to the data link layer
1.	**Begin**
2.	**Setting** analogue / decider Models
3.	**Physical layer sensitivity** - The sensitivity in [dBm] - The maximum transmission power of the physical layer [mW]
4.	**Time Management and switch times** Elapsed time to: - switch from receive to send state - switch from receive to sleep state - switch from send to receive state - switch from send to sleep state - switch from sleep to receive state - switch from sleep to send state
5.	**Setting radio channel** - State the radio is initially in (0=RX, 1=TX, 2=Sleep) - Radios gain factor (attenuation) while receiving - Radios gain factor (attenuation) while not receiving - Number of available radio channels. Defaults to single channel radio.
6.	**End**

Chapter Four

The Implementation and Results

4.1 Overview

This chapter covers the results of the work implemented in the third chapter, so the results of the Drone-SDN network will be displayed as the UAV drones implemented based on OMNET++ in Windows 7/ 32 bits with C++ programming language. Furthermore, the chapter shows the results of the implementation of the proposed system. Finally, we compare our work with related work.

4.2 Implementing proposed System in OMNET++ Environment

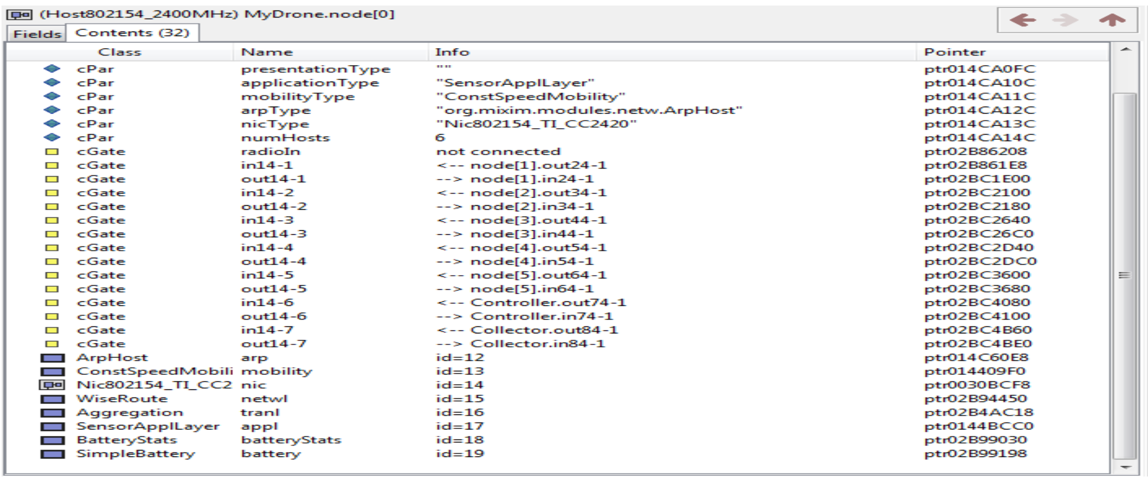
The proposed Drone module defines a drone using an IEEE 802.11ac transceiver at 5G GHz for wireless communications, that can be used to simulate an UAV drone network. The used system shows that the mobility feature minimizes the relocation distance of controllers, leading to minimizing the time of relocation and potentially preserving energy of standard controllers. The proposed system deals with the data captured within drone networks as a huge data management with the proposed simulation parameters as throughput, mean power consumption, number of captured frames and computation power.

Moreover, the main simulation parameters of the proposed system described in Table 4.1. It showed the node coordination (X, Y, Z), which it is represented by MUAV drone, with the main connection manager power setting, sensing carrier, and the configuration for mobility, network layers and the setting of Controller and collector also sorted. The power consumption model based on the different activates in the network such as (data message), control message (ack, sensing, drop, negative ack), besides to the operating system processes which they are not our interest due to the proposed system based on the simulation environment.

Table 4.1: The main configuration of the used system in OMNET++.

Simulation Parameters		Simulation Values
Play ground Size X		250 m
Play ground Size Y		250 m
Play ground Size Z		100 m
Connection Manager Power max		1.1mW
Connection Manager sat		-100dBm
Carrier Frequency		5 GHz
Network interface card(NIC) Physical Layer	Sensitivity	-100dBm
	Max TX Power	1.1mW
Mobility	Speed	2 mps
	Initial X	160 m
	Initial Y	180 m
Network Layer	Route Floods Interval	1200
	Header Length	24 bits
	Network Type	Adaptive Probabilistic Broadcast
Number of Nodes	6, 10, or 20 nodes	
Controller	scheduler-class	inet::Real Time Scheduler
	Local Port	6653
Collector	Idle time for openflow matches	5 s
	Maximum Transmission Unit (MTU)	50 B

Figure 4.1 shows the content and common setting of the runtime environment based on the OMNET++ with MiXiM library with the interfaces, network card, node connection based on gates object and configuration of mobility playground of drones elements.



Class	Name	Info	Pointer
cPar	presentationType	""	ptr014CA0FC
cPar	applicationType	"SensorApplLayer"	ptr014CA10C
cPar	mobilityType	"ConstSpeedMobility"	ptr014CA11C
cPar	arpType	"org.mixim.modules.netw.ArpHost"	ptr014CA12C
cPar	nicType	"Nic802154_TI_CC2420"	ptr014CA13C
cPar	numHosts	6	ptr014CA14C
cGate	radioIn	not connected	ptr02B86208
cGate	in14-1	<-- node[1].out24-1	ptr02B861E8
cGate	out14-1	--> node[1].in24-1	ptr02BC1E00
cGate	in14-2	<-- node[2].out34-1	ptr02BC2100
cGate	out14-2	--> node[2].in34-1	ptr02BC2180
cGate	in14-3	<-- node[3].out44-1	ptr02BC2640
cGate	out14-3	--> node[3].in44-1	ptr02BC26C0
cGate	in14-4	<-- node[4].out54-1	ptr02BC2D40
cGate	out14-4	--> node[4].in54-1	ptr02BC2DC0
cGate	in14-5	<-- node[5].out64-1	ptr02BC3600
cGate	out14-5	--> node[5].in64-1	ptr02BC3680
cGate	in14-6	<-- Controller.out74-1	ptr02BC4080
cGate	out14-6	--> Controller.in74-1	ptr02BC4100
cGate	in14-7	<-- Collector.out84-1	ptr02BC4B60
cGate	out14-7	--> Collector.in84-1	ptr02BC4BE0
ArpHost	arp	id=12	ptr014C60E8
ConstSpeedMobili	mobility	id=13	ptr014409F0
Nic802154_TI_CC2	nic	id=14	ptr0030BCF8
WiseRoute	netwl	id=15	ptr02B94450
Aggregation	tranl	id=16	ptr02B4AC18
SensorApplLayer	appl	id=17	ptr0144BCC0
BatteryStats	batteryStats	id=18	ptr02B99030
SimpleBattery	battery	id=19	ptr02B99198

Figure 4.1: The proposed content fields of SDN-Drone Network.

Furthermore, the used setting of the physical layer of SDN controller showed in the Table 4.2.

Table 4.2: SDN Controller Physical Layer.

Simulation parameters	Simulation Values
Header Length	48 bits
The strength of the thermal noise [dBm]	-110 dBm
Sensitivity	-100 dBm
maxTXPower	1.1 mW

The Controller MAC Layer setting and results showed in Table 4.3.

Table 4.3: Controller MAC Layer statistics.

Simulation parameters	Simulation Values
Length of the MAC packet header (in bits	72 bits
Size of the MAC queue	100 bits
Bit rate in bps(throughput)	25320 bps
Clear Channel Assessment detection time	0.000128s
Time to setup radio to reception state	0.001792s
Time to switch radio from Rx to Tx state	0.000192s
Tx power [mW]	1 mW
Complete MAC ack message length (in bits)	40 bits

Furthermore, the SDN Controller Battery setting and results showed in Table 4.4.

Table 4.4: SDN Controller settings.

Simulation parameters	Simulation Values
nominal battery capacity (milliamps × hours (mAH))	1000 mAh
nominal voltage	3 v
capacity is updated at least every resolution time	60 s
Battery Life = Battery Capacity in mAh / Load Current in mAh	17 rs 43 Min

The proposed system comparison based on the three case study of the drone network, and it evaluated based on the increased number of drones in the network.

4.2.1 The first case study of 6 drones Network

The first case study based on 6 drones implemented in Drone-SDN scheme and evaluated parameters as throughput, packet delivery ratio (PDR), data drop rate, end to end delay time, packet losses and drone power consumption showed in Table 4.5, while Figure 4.2 network topology of the first case study.

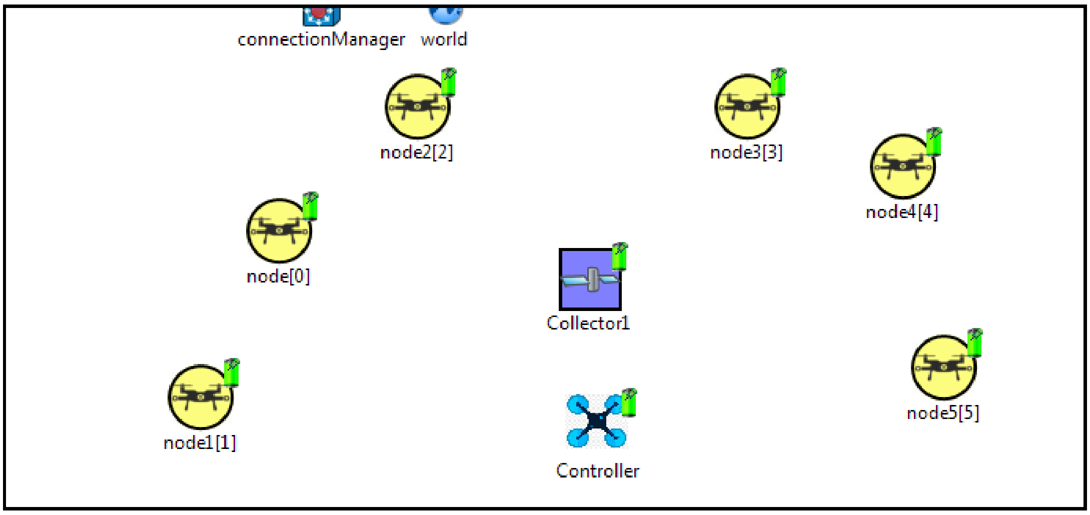


Figure 4.2: Network topology of the first case study.

Table 4.5: Simulation results of 6 drone nodes in the networks.

Drone Name	Number of Captured Packets	Packets without Interference	Packet Losses	Mean Power Consumption	Remaining Power Ratio
Drone 1	478	469	9	56.3 %	43.7%
Drone 2	463	457	6	52.6 %	47.4%
Drone 3	472	454	18	53.2 %	46.8%
Drone 4	448	439	9	51.7 %	48.3%
Drone 5	467	455	12	52.9 %	47.1%
Drone 6	551	493	58	58.2 %	41.8%
Summation	2879	2767	112	/	/
Average	479.833	461.166	18.666	54.15%	45.85%
Throughput	**9.596 KBps**				
PDR	**Packet Delivery Ratio (PDR) = 0.961 Packets/ms**				
Data Drop Rate	**0.0389 bps**				
End to End Delay Time in Seconds	**4.168 ms**				

Furthermore, the system statistics of the first case study are based on the 6 drones network shown in Figure 4. 3. The proposed system statistics showed as the number of captured packets, which means the maximum number of packets from the active Drone node in the network as acknowledge packets without errors, as the best case through it increased depending on the drone node job duty. As well, the parameter of packets without interference refers to the maximum number of packets arrived at the destination side without interference, the best results of this parameter are through the increased number as it represents the better result.

The packet losses parameter showed the number of the lost packet or dropped through the transmission journey from the source to the destination side, the best case of this parameter through the minimum number or though the decreased number of lost packets which it effects on the power consumption as the increased lost case of packets lead to decreased number of actual gather packets and mainly effected on the power consumption. Besides, the mean power consumption represents the average power consumed by drone nodes depending on the node activity of the number of capture packets as the value of power consumption increased depend on the increased number of capture packets.

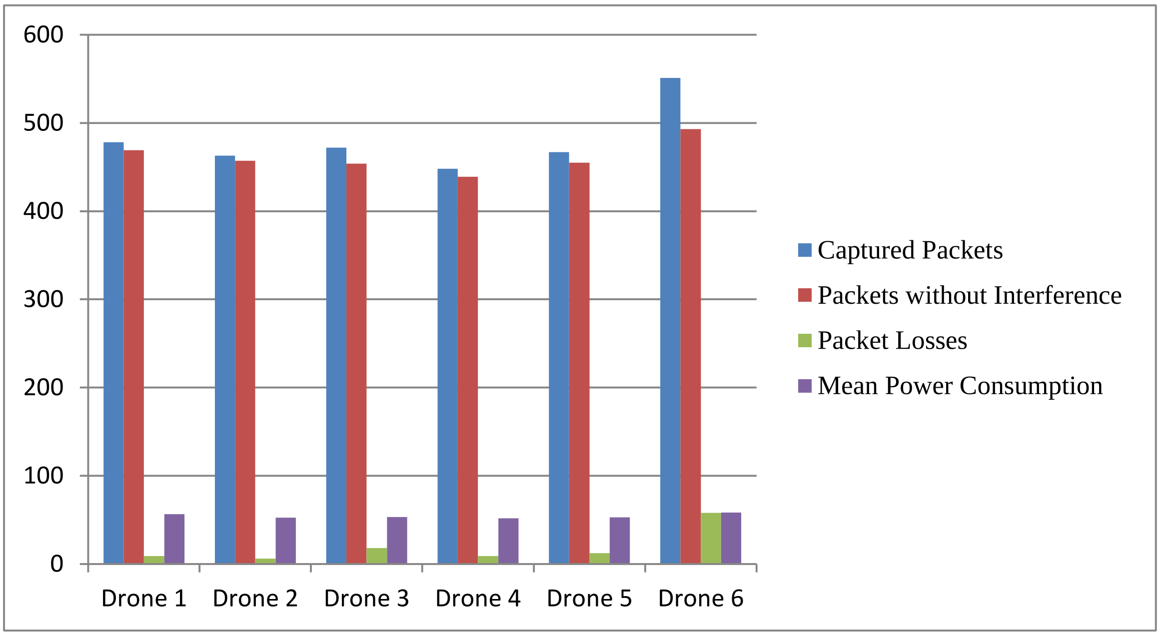


Figure 4.3: System statistics of the first case study (6 drones Network)

The proposed system evaluation parameters showed in Figure 4.4. As, the throughput measures as the amount of data traffic of captured packets based on time units and it considered the high value of

6 drones compared with other case study. Packet delivery ratio (PDR) showed the high PDR value due to the increased number of captured packets and decreased number of loose packets from entire drone nodes. Data drop rate is the least value of drop packets depending on the number of drop or negative acknowledge packets as false alarm notification packets. End to end delay showed in 6 drones case study was minimum due to the number of drones is low which effects on the active nodes in the network as which decreased number of drones lead to decreased end to end delay among drone nodes.

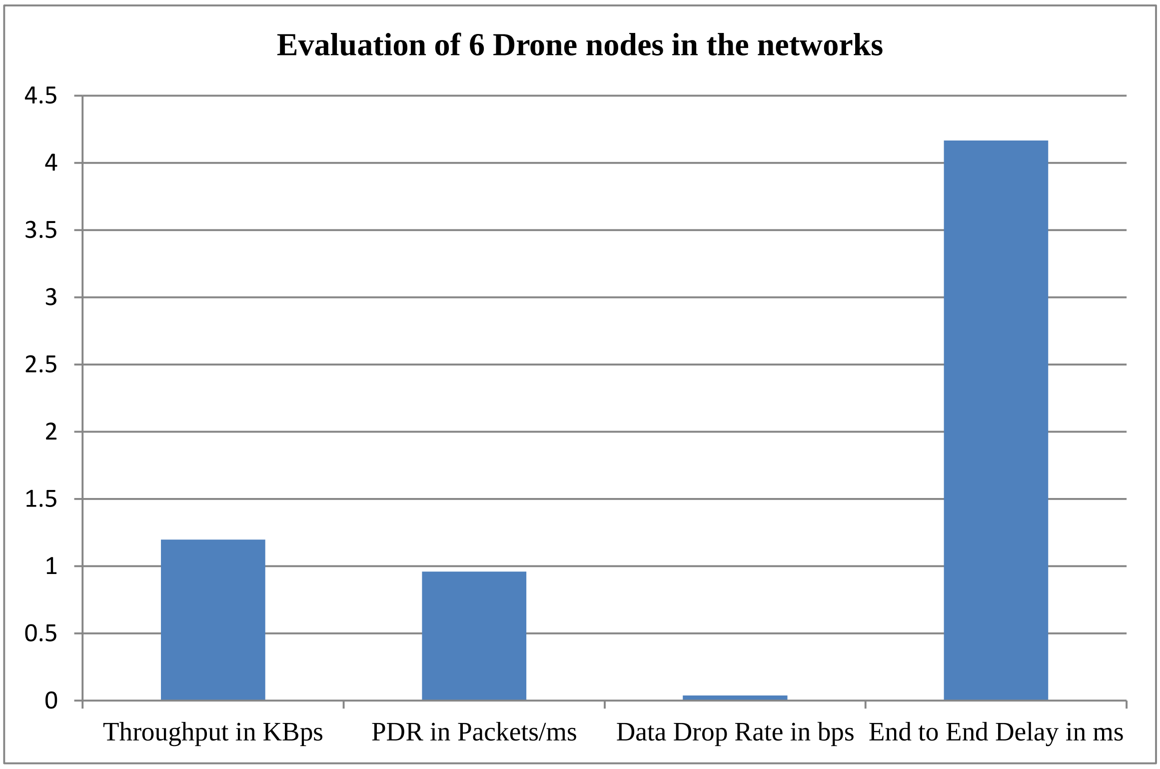


Figure 4.4: Evaluation parameters of 6 drone nodes in the networks

4.2.2 The second case study of 10 drones Network

It based on 10 drones simulated with OMNET++. Table 4.6 shows the simulation parameters of the 10 drones in the network. It showed the number of packets among drones are 2336 which effect on the number of loose packets and mean power consumption of overall drones, while the throughput and packet delivery ratio decreased, data drop rate and End to End delay are increased compared with the first case study of 10 Drones. Figure 4.5 shows the network topology of the second case study.

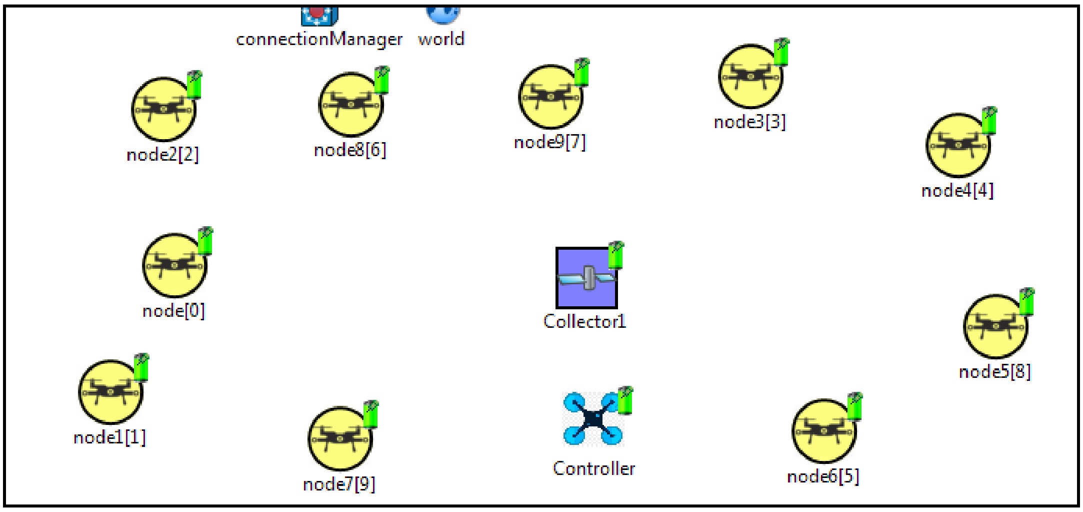


Figure 4.5: Network topology of the second case study.

In Table 4.6, the results of the 10 drones case study showed the number of capture packets decreased compared with the 1st case study (6 drones) due to the increased number of nodes causes an increased number of negative acknowledgements among 10 nodes. Besides, the number of arrived packets without interference decreased due to its relation to the number of captured packets. While, packet losses parameter increased because the lost packets from 10 drones within channel medium as they affected with interference or discarded for particular reason through the packet journey from the source to the destination, alongside mean power consumption decreased due to the job duty split depending on the increased number of drone and each node will use less power to complete the sensing/ gathering information from the environment. The remaining power ratio calculated depends on the power consumption value.

Table 4.6: The results of 10 drones in the network.

Drone Name	Number of Captured Packets	Packets without Interference	Packet Losses	Mean Power Consumption	Remaining
Drone 1	223	210	13	24.53%	75.47%
Drone 2	235	219	16	25.85%	74.15%
Drone 3	231	202	29	25.41%	74.59%
Drone 4	244	204	40	26.84%	73.16%
Drone 5	241	213	28	26.51%	73.49%
Drone 6	226	207	19	24.86%	75.14%
Drone 7	225	202	23	24.75%	75.25%
Drone 8	257	200	57	28.27%	71.73%
Drone 9	244	201	43	26.84%	73.16%
Drone 10	210	196	14	23.1%	76.9%
Summation	2336	2054	282	/	/
Average	233.6	205.4	28.2	25.696%	74.304%
Throughput	**7.786 KBps**				
PDR	**Packet Delivery Ratio (PDR) = 0.879 Packets/ms**				
Data Drop Rate	**0.1207 bps**				
End to End Delay Time in Seconds	**5.137 ms**				

Besides, Figure 4.6 shows the simulation parameters of the second case study based on captured packets, packets arrived without interference packet losses and mean power consumption.

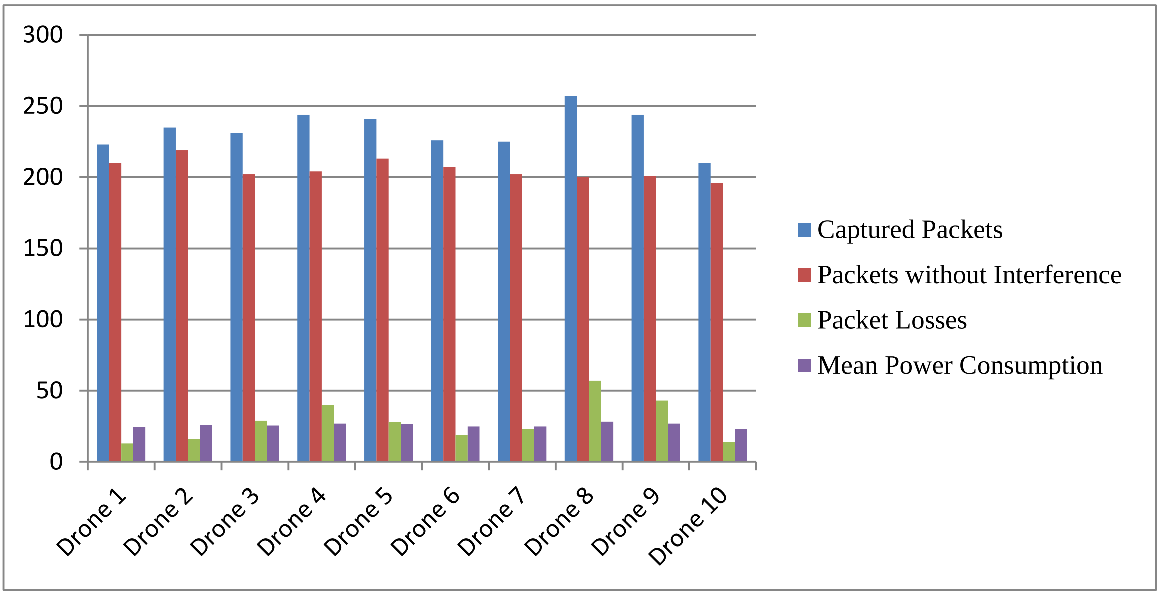


Figure 4.6: System statistics of second case study (10 drones Network)

While the proposed system evaluation parameters showed in Figure 4.7.

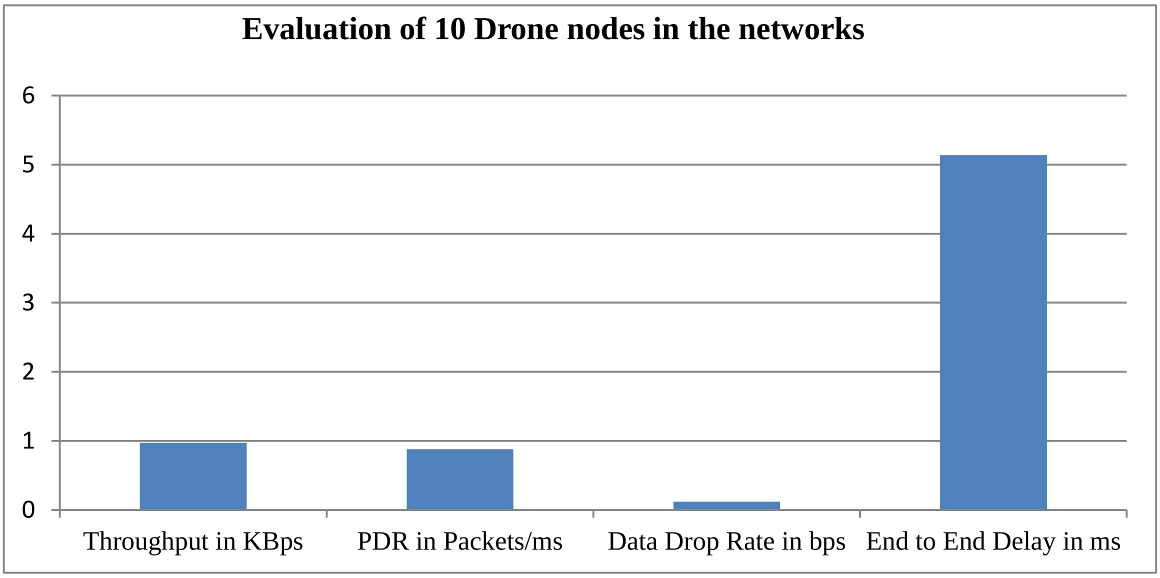


Figure 4.7: Evaluation parameters of 10 drone nodes in the networks.

4.2.3 The third case study of 20 drones Network

The third case of 20 numbers of drones shows in Table 4.7. The comparative case study showed that the 20 drones effects on packets lose, throughput, packet delivery ratio decreased, data drop rate and end to end delay are increased compared with the 10 drones case. Figure 4.8 shows network topology of the third case study.

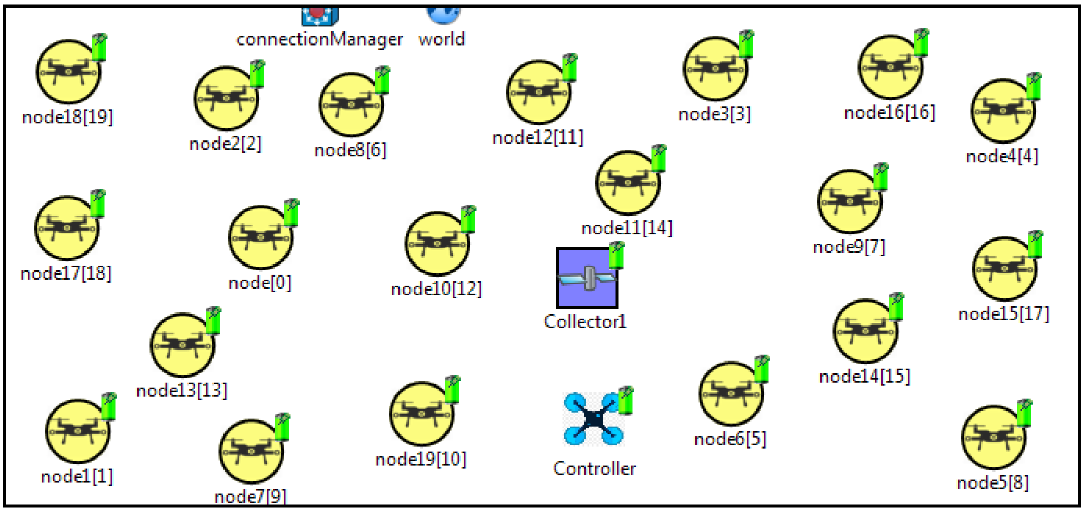


Figure 4.8: Network topology of the third case study.

Table 4.7 showed the number of active nodes as 20 drones and the number of capture packets decreased compared with 1st and 2nd case studies due to the job divided among nodes to complete duty and they will complete job duty early by dividing the main data gathering information among them. While the packets arrived without interference decreased due to the relation between the number of captured packets with arrived packets without interference. Alongside, the packet losses increased due to increased number of drones which it causes increased number of false alarms or discarded packets from the source to the destination, while the mean power consumption by drone node decreased due to the activity a signed for each node and the relation among captured packets and consumed power. So the drone lifetime will increase due to the decreased number of the captured packets by each drone node.

Table 4.7: The results of 20 drones in the Network.

Drone Name	Number of Captured Packets	Packets without Interference	Packet Losses	Mean Power Consumption	Remaining Power Ratio
Drone 1	77	52	25	8.47%	91.53%
Drone 2	72	55	17	7.92%	92.08%
Drone 3	66	51	15	7.26%	92.74%
Drone 4	63	57	6	6.93%	93.07%
Drone 5	75	60	15	8.25%	91.75%
Drone 6	70	50	20	7.7%	92.3%
Drone 7	73	51	22	8.03%	91.97%
Drone 8	72	54	18	7.92%	92.08%
Drone 9	75	58	17	8.25%	91.75%
Drone 10	68	51	17	7.48%	92.52%
Drone 11	67	49	18	7.37%	92.63%
Drone 12	66	43	23	7.26%	92.74%
Drone 13	74	47	27	8.14%	91.86%
Drone 14	72	50	22	7.92%	92.08%
Drone 15	67	52	15	7.37%	92.63%
Drone 16	76	55	21	8.36%	91.64%
Drone 17	69	46	23	7.59%	92.41%
Drone 18	66	42	24	7.26%	92.74%
Drone 19	63	48	15	6.93%	93.07%
Drone 20	79	44	35	8.69%	91.31%
Summation	1410	1015	395	/	/
Average	70.5	50.75	19.75	7.755%	92.245%
Throughput		**4.7 KBps**			
PDR		**Packet Delivery Ratio (PDR) = 0.719 Packets/ms**			
Data Drop Rate		**0.2801 bps**			
End to End Delay Time in Seconds		**8.510 ms**			

Also Figure 4.9 shows the results from the third case study based on the used system statistics parameters.

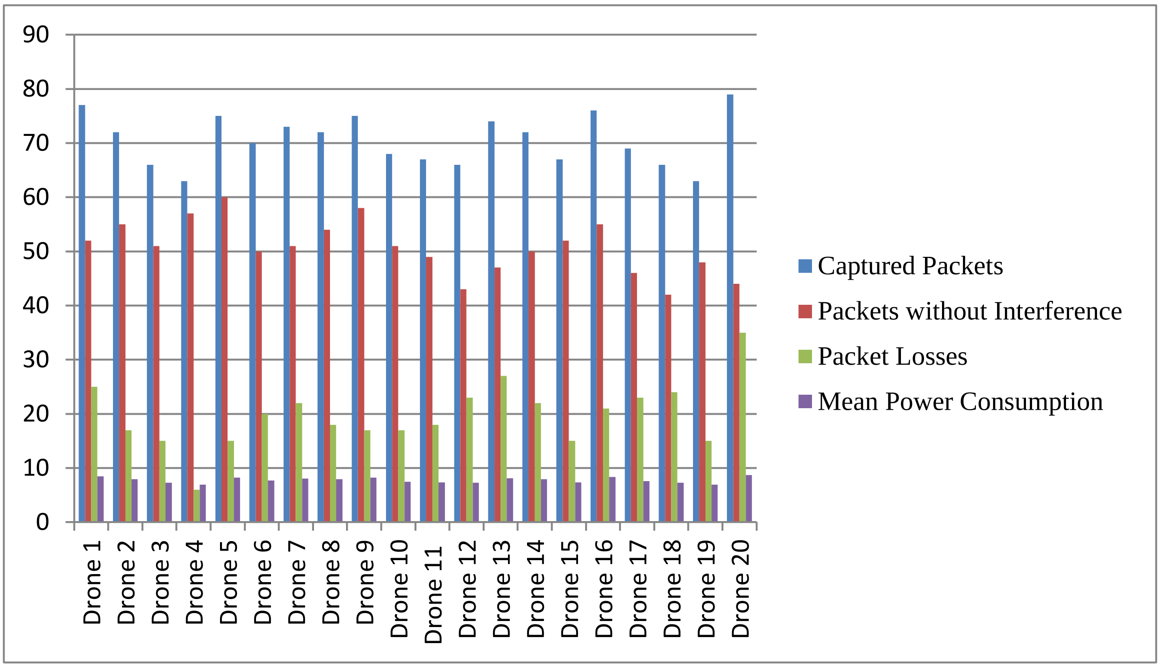


Figure 4.9: System statistics of the third case study (20 drones Network)

The proposed system evaluation parameters showed in Figure 4.10.

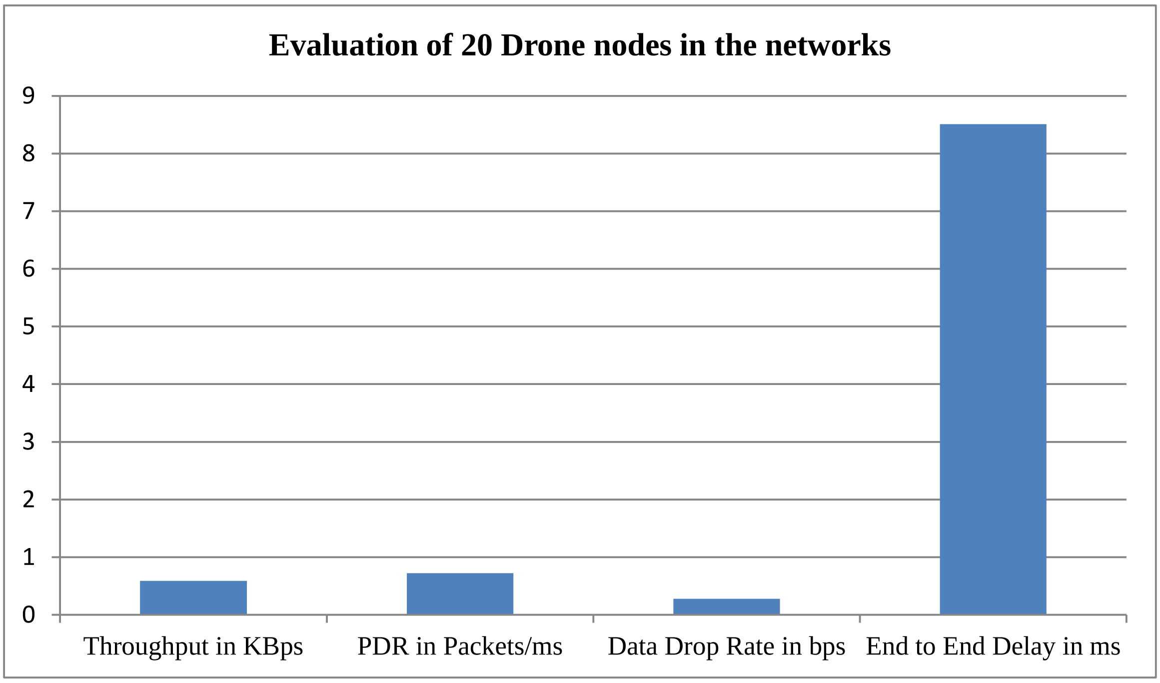


Figure 4.10: Evaluation parameters of 20 drone nodes in the networks

4.3 Building another type of network that contains more than one collector

The main goal of multiple collectors in the proposed system to provide (scalability, consistency, reliability, load balancing). In the case of scalability of multi-collectors to cope with single controller problem (single point of failure, limited control resources, etc.). Besides, it is necessary to guarantee the consistency of the multi-collector. Meanwhile, different types and locations of collectors may suffer from indeterminate failure and indeterminate attack (interference), which influence the reliability of the control plane. Besides, the unbalanced distribution of collector loads will degrade the network performance.

4.4 System Comparisons

Besides the simulation results of the drones nodes in the network showed in the Figure 4.11 and Table 4.8,4.9. As mentioned to get better network performance depending on determining the accurate number of drones it does not matter necessary to increase the number of drones but it should base on the accurate and appropriate number of drones for the specific network application. The proposed system shows the first case study (6 drones) better network performance compared with the other case studies as the throughput in 9.596 KBps, PDR in 0.961 Packets/ms, data drop rate 0.0389 bps, average packet losses 18.666 of (2879) number of captured packets and end to end delay time 4.168 ms.

Table 4.8: System Comparison based on different Case Studies of One Collector.

With One collector					
No.Of Drones	**Throughput in KBps**	**PDR in Packets/ms**	**Data Drop Rate in bps**	**Avg Packet Losses**	**End to End Delay Time in ms**
6 Drones	9.596	0.961	0.0389	18.666	4.168
10 Drones	7.786	0.879	0.1207	28.2	5.137
20 Drones	4.7	0.719	0.2801	19.75	8.51

Table 4.9: System Comparison based on different Case Studies of Two Collector.

With Two collector (Synchronize Collector)					
No.Of Drones	**Throughput in KBps**	**PDR in Packets/ms**	**Data Drop Rate in bps**	**Avg Packet Losses**	**End to End Delay Time in ms**
6 Drones	9.691	0.970	0.039	18.852	4.209
10 Drones	7.941	0.896	0.1231	28.764	5.239
20 Drones	4.935	0.754	0.2941	20.737	8.935

The case of the two synchronize collectors showed the best results from the PDR due to the amount of time of active drone nodes and data transmitted for the idle channel is better and it covers the increased number of drone nodes in the network which reflects the results on the entire network performance. The power consumption parameter increased due to the drone node transmit more data which requires more power to achieve the goal.

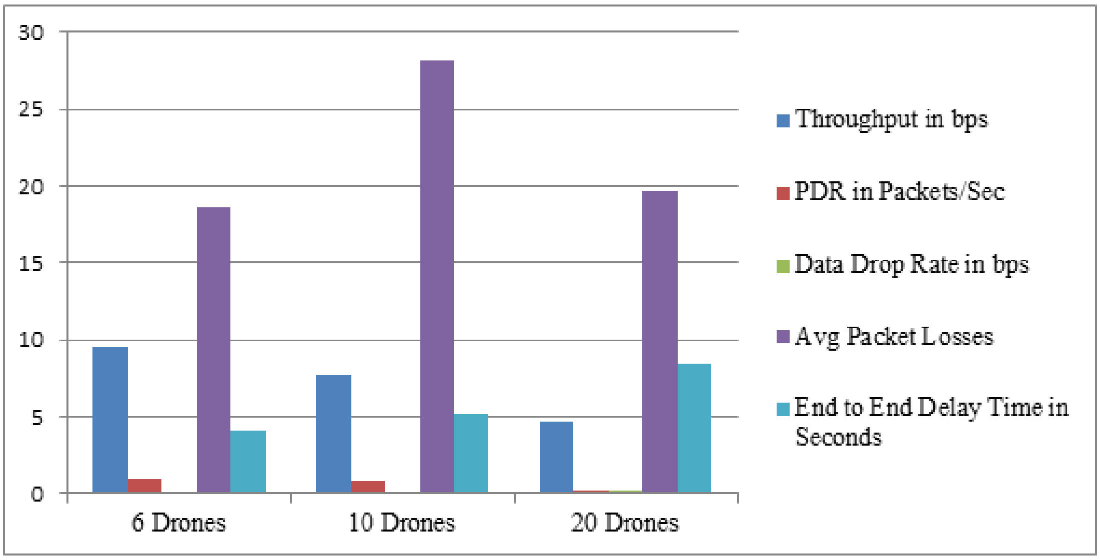


Figure 4.11: The used system comparisons among three case studies.

Also, the log file from the proposed system showed in the Figure 4.12 as the log file show the drone network elements behavior within SDN framework as it contains on transmission over, route flood, node hand off and handover states for channel acquisition.

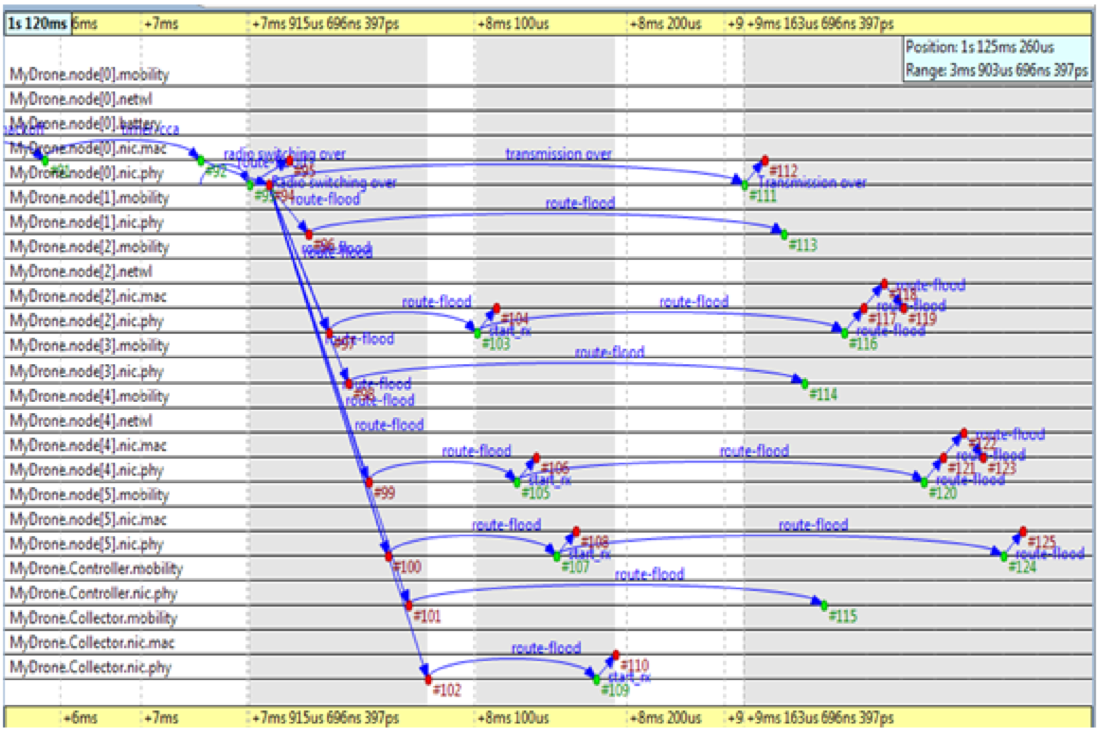


Figure 4.12: Log File of the proposed system.

The proposed system compared with hybrid path planning for efficient data collection in UAV-Aided WSNs for emergency applications. It based on a hybrid path planning (HPP) algorithm for efficient data collection by assuring the shortest collision-free path for UAV in emergency environments. The probabilistic roadmap (PRM) algorithm is used to design the shortest trajectory map and the optimized artificial bee colony (ABC) algorithm to improve different path constraints in a three-dimensional environment. The evaluation parameters used as Packet delivery ratio, power consumption and remaining power ratio which it explained entire network life time depending on the drone nodes. Table 4.10 showed the system comparison [17].

Table 4.10: System comparison with related work.

No.Of Drones		**PDR in Packets/ms**	**Average Power Consumption**	**Remaining Power Ratio**
Proposed 6 Drones	One Collector	0.961 %	54.15%	45.85 %
Proposed 10 Drones		0.879 %	25.696	74.304 %
Proposed 20 Drones		0.2801 %	7.755%	92.245% %
Proposed 6 Drones	Two Collector	0.970 %	54.691 %	45.309 %
Proposed 10 Drones		0.896 %	26.209 %	73.791%
Proposed 20 Drones		0.2941 %	8.142 %	91.858 %
ABC 10 Drones[17]		0.787%	32.02%	67.8%
ABC 20 Drones[17]		0.789%	38.02%	61.98%
PRM 10 Drones[17]		0.778%	30.2%	69.8%
PRM 20 Drones[17]		0.779%	40.9%	59.1%
Hybrid 10 Drones[17]		0.791%	31.05%	68.95%
Hybrid 20 Drones[17]		0.805%	39.6%	60.4%

Chapter Five

Conclusion and Suggestions For Future Work

5.1 Conclusions

The major aim of this thesis is to design and build a network of drones based on software-defined network (SDN) technology and taking advantage of the benefits and properties of this technique to address the challenges of resource management and network management, as well as solve the problem of power consumption, which are the challenges that drone networks face in this work. Then, simulation the proposed network in OMNET++ with C++ programming language.

There are few existing solutions to improve computation power and resource management within simulation drones-SDN networks compared with different research for real hardware implementation. anyway, the main conclusion of this work are listed below:

- Building a network of drones, the single point of failure problem was solved which would have led to the failure of the mission in the event that the drone was exposed to any malfunction when operating alone.
- The proposed system was evaluated based on Throughput, Packet Delivery Ratio (PDR), Data Drop Rate, End to End Delay Time, Packet Losses, and Drone Power Consumption. As the use of SDN in building the network leads to the use of the least number of hardware possible. thus executing the task with the fewest number of drone nodes at the same time, we get better results. in other words, the use of SDN will reduce the number of network nodes and thus improve the results of all the parameters mentioned. As a result, it solves the problem of resource management and network. The results summarized as Throughput is 9.596 bps, PDR is 0.961 Packets/Sec Drop Rate of Data is 0.0389 bps, while Delay Time is equal to 4.168 seconds for the 6 drones case study.

Alongside, Throughput is 7.786 bps, PDR equal to 0.879 Packets/Sec Drop Rate is 0.1207 bps, Delay Time is 5.137 seconds of 10 drones case study. While the third case of 20 numbers results as follows: Throughput equal 4.7 bps, PDR is 0.719 Packets/Sec, Drop Rate is 0.2801 bps, and Delay Time is 8.510 seconds.

- The proposed system enhanced drone network implementation based on SDN architecture as the management network traffic enhanced through data traffic controlled by controller and collector to eliminate congestion and decrease traffic load and analysis collecting the required data accurately from drones compared with traditional drone network without SDN.

5.2 Suggestions for Future Works

The use of drones is an emerging and evolving technology. And Its applications in many and different fields. After applying the proposed work, some future works can be listed:

1- Adding thermal cameras on drones and using the network to monitor and protect the borders, which contributes to combating terrorism, smuggling, and others.

2- Network development and use in the field of vehicle traffic control on the streets. This contributes to relieving traffic jams and reducing accidents, as well as recording traffic violations.

3- Expand the network and build it in the form of distributed networks, that contain more than one controller distributed in multiple areas and synchronized between them. and can use this network in wide applications.

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جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل / كلية تكنولوجيا المعلومات
قسم شبكات المعلومات

طائرات بدون طيار يتم التحكم فيها ديناميكيًا استنادًا الى الشبكات المعرفة بالبرمجيات

رسالة مقدمة

إلى مجلس كلية تكنولوجيا المعلومات في جامعة بابل كجزء من متطلبات

الحصول على درجة الماجستير في تكنولوجيا المعلومات / شبكات المعلومات

من قبل

احمد زكي وفي جاسم

بأشراف

أ.م. د. الحارث عبد الكريم عبد الله   أ.م. د. احمد مهدي محمد الصالح

1443 هـ   2021 م

الخلاصة

أن الطائرات بدون طيار هي روبوتات طيران لديها القدرة على السفر لمئات الكيلومترات ويمكن التحكم فيها عن بعد أو يمكنها الطيران بشكل مستقل باستخدام خطط الطيران المبرمجة. في السنوات الماضية، تطورت تكنولوجيا الطائرات بدون طيار أو المعروفة أيضًا باسم المركبات الجوية بدون طيار (UAV) بسرعة كبيرة واستخدمت على نطاق واسع في العمليات العسكرية والإنقاذ الطبي والمراقبة البيئية وغيرها من المجالات. من جهة اخرى، الشبكات المعرفة بالبرمجيات (SDN) هي الشبكات القادمة واسعة الانتشار والجديرة بالثقة والمرنة للمستقبل. جذبت قابلية البرمجة ونظام التحكم المركزي لشبكة SDN العديد من الباحثين والعلماء وشركات التصنيع لإجراء البحوث وتنفيذها.

هناك العديد من المشاكل التي تواجهها الطائرة بدون طيار عندما تعمل بصورة منفردة لأنها تعتبر نقطة واحدة للفشل وأيضا سهلة التدمير والسرقة والاختراق. من ناحية اخرى، هناك العديد من التحديات التي تواجه شبكات الطائرات بدون طيار، لكن إدارة الموارد، واستهلاك الطاقة تعتبر من المشاكل الرئيسية التي تواجه شبكات الطائرات بدون طيار.

في هذه الرسالة، تم تصميم وبناء شبكة من الطائرات بدون طيار تعتمد على تقنية SDN لاستخدام هذه الشبكة في مجالات وتطبيقات متعددة. حيث تعمل الطائرات بدون طيار كعقدة للشبكة لجمع البيانات في مستوى البيانات وفي مستوى التحكم لدينا وحدة تحكم SDN موجودة في المحطة الأرضية. علاوة على ذلك، تمت إضافة المُجمع في هذه الطبقة، وهو عبارة عن طائرة بدون طيار تعمل كقناة لتوصيل عُقد الشبكة بوحدة تحكم SDN إلى جانب ذلك، تم اقتراح بروتوكول يقوم بإجراء التزامن بين هذه المجمعات في الشبكة. تمت محاكاة الشبكة المقترحة باستخدام بيئة المحاكاة + OMNET.

تم تقييم النظام المقترح بناءً على الانتاجية، ونسبة تسليم الحزم (PDR)، ومعدل اسقاط البيانات، ووقت التأخير، وخسائر الحزم، واستهلاك طاقة الطائرات بدون طيار. أظهرت النتائج التي تم الحصول عليها أنه من خلال بناء الشبكة على أساس بنية SDN، هناك تحسن في إدارة الشبكة واستهلاك الطاقة.