

Building Flexible Drone Networks based on SDN

Ahmed Z. Wafi

College of Information Technology, University of Babylon, Babil, Iraq.
E-mail: ahmed.wafi@student.uobabylon.edu.iq

Ahmed M. Al-Salih

College of Information Technology, University of Babylon, Babil, Iraq.
E-mail: ahmed.alsalih@uobabylon.edu.iq

Alharith A. Abdullah

College of Information Technology, University of Babylon, Babil, Iraq.
E-mail: alharith@itnet.uobabylon.edu.iq

Received August 02, 2021; Accepted November 20, 2021

ISSN: 1735-188X

DOI: 10.14704/WEB/V19I1/WEB19012

Abstract

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. the programmability of Drone and self-leading are being the key point of future transportation and safety. Simultaneously, Software-Defined Networks (SDN) the upcoming widespread, trustworthy, and flexible networking for the future. The programmability and center control system of the SDN network It the most important features. that resource management and power-consuming is the main problem faced in the Drone environment. In this paper, we design a Drones network based on Software Defined Network (SDN) to solve these problems. moreover, simulation the proposed network in OMNET++ simulation tool. 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. The results show enhancement in network performance through the results obtained.

Keywords

Drone, UAVs, SDN, Dynamic Controller, Collector, SDN-Drones.

Introduction

Recently, drones or aerial vehicle UAV technology 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 (Erdelj, *et al*, 2017). Drones have gained very great importance because they are easy to set up and have low costs (Yanmaz *et al*, 2018). Drones play an important role in facing difficult risks and tasks, thus reducing material losses from infrastructure and human beings (Euchi, J. 2020; Liu *et al* 2014). Software-Defined Networks (SDN) is a method of network management that enables dynamic, programmatically efficient network configuration in order to ameliorate network performance and monitoring, that makes these networks more like cloud computing, and this is what distinguishes them from traditional networks (E. Haleplidis *et al*, 2015).

In addition, as it provides the network administrator with the ability to separate the level of control from the level of data and the level of applications in networks. This makes it more flexible as this aspect helped reduce the cost and optimally manage the services provided by the network and help reduce overloading traffic, as well as increasing the security and availability of the network (Xiao Zhang *et al*, 2018). Central control within SDN network components is a perfect fit for drone applications. As the SDN control provides a stable and efficient connection in a network because it contains a regular link, and the nature of the Drones network changes due to the movements of UAV Drones in different directions (Chetna Singhal *et al*, 2020; Gökhan Seçinti *et al*, 2018). So SDN provides flexibility in network management, timely aware delivery of content, and the large capacity to process data traffic in the network. As well as getting quality of service for many network protocols (Vashisht *et al*, 2019; Zhang *et al*, 2018). There are many relevant research directions that suggest systems and methods for cooperation between SDN networks and Drones networks. we are summarized some of these research as follow: In (M.F. Bari *et al*, 2013; De Bruin *et al*, 2015) this work, the researchers focused on monitoring the necessary infrastructure for transport between nodes in Drones networks, especially in remote areas. Where communications and computing play an important role for real-time applications same as when monitoring data traffic based on computer vision techniques. The results showed that the proposed system improves network efficiency and reduces damages by 81% and the successful implementation of the UAV in the field of control algorithms. While in (Motlagh *et al*, 2017; Elloumi *et al*, 2018) they discuss the topic of restrictions resulting from the use of traditional video cameras and how these restrictions were reduced by using UAVs drones. This is by proposing an almost automated, low-cost method for extracting detailed vehicle paths by relying on footage provided by drone video cameras. It has been dealt with to reduce the errors resulting from the instability of the cameras. The results proved that the proposed

system can rely upon UAVs to replace or expand the current systems and avoid the errors resulting from them in this field. In (Yuan et al, 2016) they have been suggested an SDN framework based on mobile sensor network for group micro unmanned aerial vehicles (MUAV). The proposed system depends on the construction of a centralized management unit for remote control, which is linked to the Swarm SDN-Controller through the cloud, which is connected to the UAV network. The results showed that the proposed system reduces network resource consumption compared to the traditional network. It also reduces the complexity involved in route algorithms. In (Rahman et al, 2018; A. Alshamrani et al, 2018; M. Tanha et al, 2018) other works The researchers focused on ensuring reliability, increasing tolerance for errors, and the need to ensure the availability of control units, as they were studied computation limited and controlled management. The results proved that the proposed system deals accurately to improve these concepts through linking and making use of SDN controller by controlling the load in the network as well as regulating resource management. In (Karaduman et al, 2019) adopt Video data analysis method acquired from Drones networks. This is done by detecting video recordings based on two algorithms as k-Nearest Neighbor and Hough transformation algorithms to analyze video captured by drones and use the fuzzy approach to classify the road type. The results showed that the proposed system has the ability to find experimental methods in aerial photographs. In (Kumar et al, 2021), A scheme based on the use of the minimum required number of UAVs 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.

The outline of the paper can be sketched in the following way: Section II presents the proposed system as the implementation of Dynamic controller provisioning in SDNs with C++ programming in OMNET++ in Windows 7. Section III presents the proposed scheme of SDN controller in Drone Network. As for Section IV, the simulation results and performance analysis are provided; Section V evaluation the proposed scheme. The concluding remarks are stated in Section VI.

The Proposed System

The proposed system based on the OMNET++, MIXIM extension and build code with C++. We simulate the Drones or Autonomous Unmanned Aerial Vehicles (UAVs) with Software Defined networking technology (SDN) controller management, The goal of using drones is to reduce the resulting cost from the movement of data within the network and reduce or eliminate the risks resulting from sending a human to difficult or impossible

areas and may affect his life, while the goal of using SDN is enhancing monitoring, network performance, decreasing network overhead in resources constraints like drones sensor networks also it enhanced optimal decision intelligently in Drone network.

The proposed system based on the SDN and Drone architecture in Figure 1, which it consists of:

- Data plane as Drone's nodes to gather data.
- Controller plane as:
 - Collector to connect and manage data from the source nodes.
 - Ground station (SDN controller) which it responsible on data flow and data analysis with application layers to building system results.
- Application Plane

The controller is most important part of SDN networks. Also, its placement has a great impact on the performance of the network. In this work, the controller was placed inside the ground station for several factors, of which are security problems, ease of control and management, and solving energy problems, because stopping the controller will lead to the entire network being stopped. On the other hand, the collector has been added to control plane as a Drone. It acts as a channel to connect the network nodes to the - controller, as well as performing simple control tasks and facilitating the transfer of data and commands from the controller to nodes and vice versa. It also has an important role in improving network performance and increasing the communication space and many other benefits. 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. The main simulation parameters of the proposed system described in Table 1

Table 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
Connection Manager.pMax		1.1mW
Connection Manager.sat		-100dBm
Carrier Frequency		2.4GHz
Network interface card (NIC) Physical Layer	Sensitivity	-100dBm
	maxTXPower	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	N	
Controller	scheduler-class	inet::RealTimeScheduler
	localPort	6653
Collector	Idle time for openflow matches	5 s
	Maximum Transmission Unit (MTU)	1500B

The architecture of the used network showed in the Figure 1.

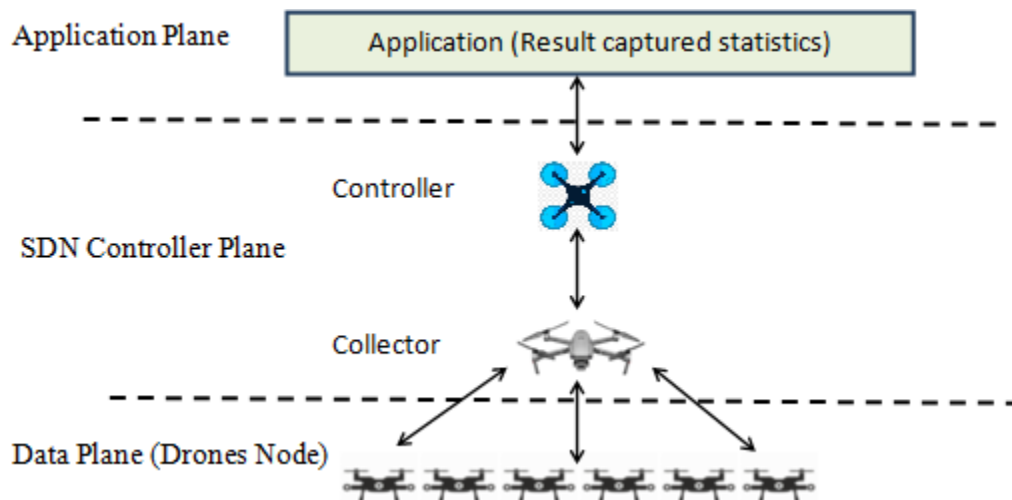


Figure 1 Architecture of Drone Network based on SDN

Implementation of the Proposed System

The implementation of the proposed system based on the two sections in the simulation environment as shown in figure 2.

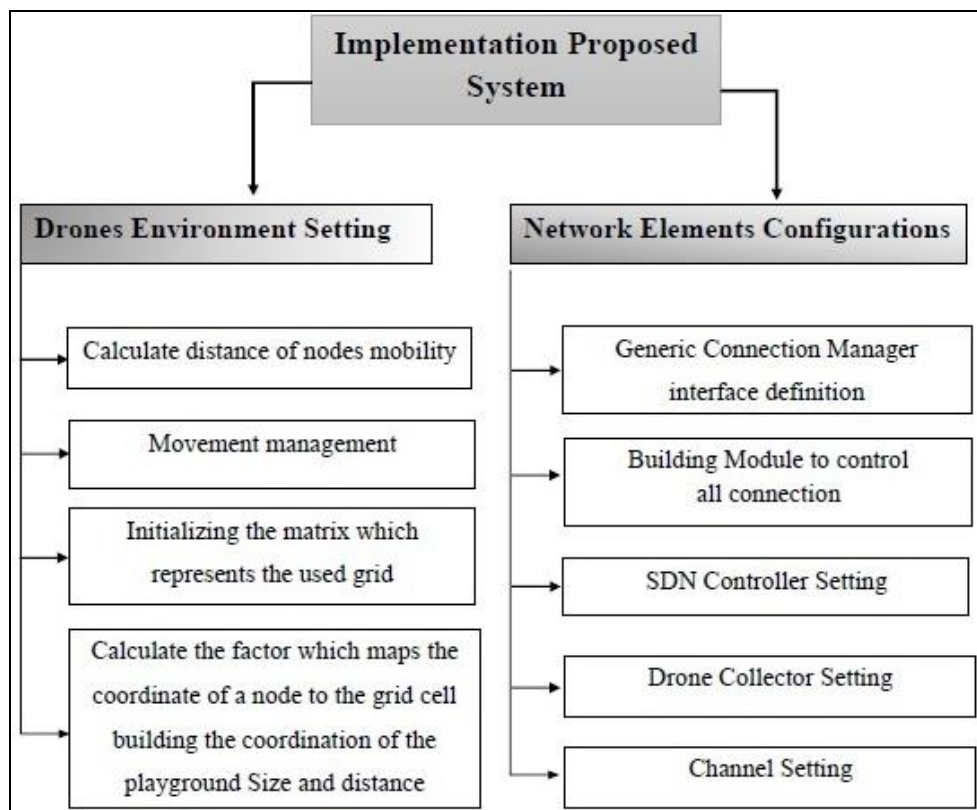


Figure 2 Implementation of the Proposed System

Besides, the used SDN module algorithm is explained in Algorithm 1.

Algorithm 1 The used SDN controller module Algorithm

SDN Controller Module Algorithm	
1-	Import libraries package from INET extension - inet. applications. contract. IApp
2-	Initializing parameters for Controller socket - Local Address = default("10.1.1.1"); - Local Port = default(6633) used to listen on some openflow and controller State Flow parameters - ACK Interval @unit(ms)=default(100ms) - Messages Waiting Interval @unit(ms)=default(1000ms) for data messages - features Waiting Interval @unit(ms)=default(500ms) as waiting for specific Features in data capture State from Drones - Time synchronize for idle and hard (0-5) - Logging errors to file - set capturing interface filter to "any"
3-	Data processing - xml flow for system application - IP address of DB - DB port setting - Name of DB user - DB password (optional) - Event recording - socket configuration with - socketIn/ socketOut with TcpCommand
End of algorithm	

Besides, the packet NetwPkt features simulated as in the Algorithm 2:

Algorithm 2 The used network layer packet class

Pseudo code of network layer packet packetNetwPktAlgorithm	
Step 1: Building the constructor of destination address from the main class - LAddress::L3Type destAddr;	
Step 2: Building the constructor of source address - LAddress::L3Type srcAddr	
Step 3: Configuring the number of hops for each node based on time to live field (TTL) - ttl = 1;	
Step 4: Adding signed long sequence number - seqNum = 0	
End of Algorithm	

Furthermore, BasePhyLayer algorithm steps showed in Algorithm 3, as:

Algorithm 3 Building Base Physical Layer Algorithm

<p>Phase 1: Initializing parameters</p> <ul style="list-style-type: none">- debug switch for core framework- enable/disable tracking of statistics- defines the length of the phy header (/preamble) <p>Phase 2: Setting analogue Models</p> <ul style="list-style-type: none">- Specification of the analogue models to use and their parameters- Specification of the decider to use and its parameters <p>Phase 3: Physical layer sensitivity</p> <ul style="list-style-type: none">- The sensitivity of the physical layer [dBm]- The maximum transmission power of the physical layer [mW] <p>Phase 4: Time Management and switch times</p> <ul style="list-style-type: none">- Elapsed time to switch from receive to send state- Elapsed time to switch from receive to sleep state- Elapsed time to switch from send to receive state- Elapsed time to switch from send to sleep state- Elapsed time to switch from sleep to receive state- Elapsed time to switch from sleep to send state <p>Phase 5: Setting radio channel</p> <ul style="list-style-type: none">- 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. <p>Phase 6: Making Setting for gates</p> <ul style="list-style-type: none">- input upperLayerIn: From the MAC layer- output upperLayerOut: To the MAC layer- input upperControlIn: Control from the MAC layer- output upperControlOut: Control to the MAC layer- input radioIn: For sendDirect from other physical layers
End of algorithm

Implementation Results

The proposed Drone module defines a drone using an IEEE 802.15.4 transceiver at 2.4GHz for wireless communications, that can be used to simulate a Drone network. The dynamic diagram shows that the proposed system reduces the control transmission distance, reduces reconfiguration time and maintains the amount of energy consumption. The proposed system deals with the data captured within drone networks as huge data management with the proposed simulation parameters as Throughput, Mean Power Consumption, Number of Captured Frames and computation power.

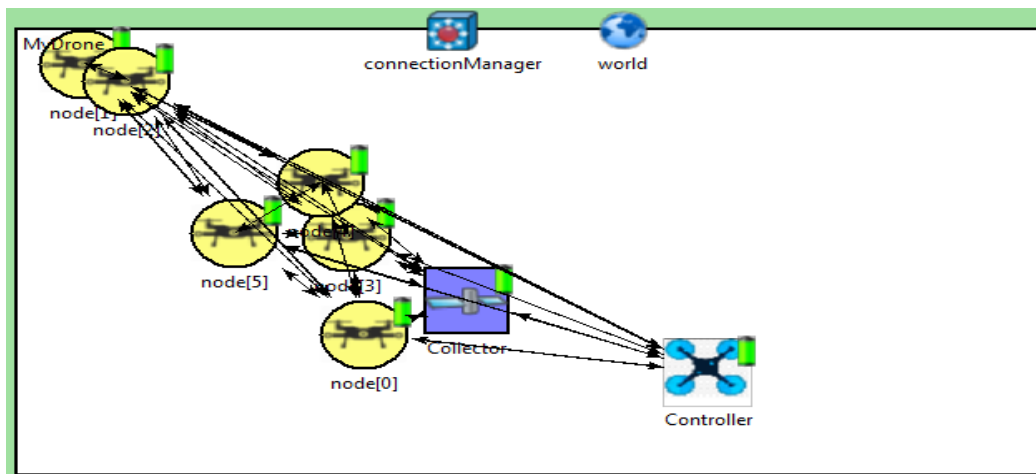


Figure 3 The proposed network topology of SDN-Drone Network

Comparative Study

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 and the evaluation parameters used explained as follow:

Packet Delivery Ratio (PDR): It is one of the important metrics to know the ratio of the number of packets successfully received to the destination and the number of packets sent (Khan et al, 2013):

$$PDR = \frac{P_{Received} * 100\%}{\sum_{i=1}^n P_{generated_i}} \quad (1)$$

Data Drop Rate is represented as the ratio of the difference between the total number of packets sent and the total number of packets received to the total number of packets sent, and the used equation is (Kaur et al, 2016):

$$Data\ Drop\ Rate = \frac{Total\ no.of\ Sent\ Packets - Total\ no.of\ Recieved\ Packets}{Total\ Number\ of\ Sent\ Packets} \quad (2)$$

Delay time is representing the time given for sending packets from the first sending party to the second receiving party based on the following equation(Khan et al, 2020):

$$d_{trans} = L \quad (3)$$

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.

Throughput of the network (bps) over number of nodes for variable packet sizes. For each packet size, it is worth noting that the number of packets in the network decreases with the increase in the number of nodes in the network in drones because the probability of error and packet loss increases with the increase of these nodes. This results in a lower rate of data transfer.

Furthermore, in addition, the probability of error is affected by increasing the size of the packet as a result of its fragmentation, where the level of decay of a small packet is less than the level of decay of a large packet to increase the probability of error. This situation makes the estimated decrease in productivity within the network be greater.

Whilst loose packets as depicts number of packets lost versus number of nodes for variable packet sizes. For each packet size, the number of lost packets increases with an increase in the number of Drone nodes between the source and the destination. Increasing the number of nodes causes an increase in the probability that the packet may be dropped while it competes to access the wireless channel at each node to reach its destination. However, when this increase occurs, the number of lost packets will decrease the Packet Transmission Ratio (PTR). The decreasing level of PTR for smaller packet size is less than the decreasing level of PTR for a bigger one, because packet error probability increases as packet size increases, which leads to an increase in the number of lost packets and this case makes the decrease in PTR larger for large packet size. 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 2.

Table 2 Simulation parameters from 6Drone nodes in the networks.

Drone Name	Number of Captured Packets	Packets without Interference	Packet Losses	Mean Power Consumption
Drone 1	478	469	9	56.3 %
Drone 2	463	457	6	52.6 %
Drone 3	472	454	18	53.2 %
Drone 4	448	439	9	51.7 %
Drone 5	467	455	12	52.9 %
Drone 6	551	493	58	58.2 %
Summation	2879	2767	112	/
Average	479.833	461.166	18.666	/
Throughput	9.596 bps = 1.1995 Bps			
PDR	Packet Delivery Ratio (PDR) = 0.961 Packets/Sec			
Data Drop Rate	0.0389 bps			
End to End Delay Time in Seconds	4.168 s			

While Table 3 show the simulation parameters of the 10 Drones in the network. In addition, the second case of 10 Drones 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 6 Drones.

Table 3 The results of 10 Drones in the network

Parameter for 10 drones	Number of Captured Packets Of 10 drones	Packets without Interference	Packet Losses	Mean Power Consumption
Summation	2336	2054	282	51.7 %
Average	233.6	205.4	28.2	/
Throughput	7.786 bps = 0.97325 Bps			
PDR	Packet Delivery Ratio (PDR) = 0.879 Packets/Sec			
Data Drop Rate	0.1207 bps			
End to End Delay Time in Seconds	5.137 s			

While the third case of 20 numbers of drones shows in Table 4. The comparative case study showed that the 20 Drones effects on packets loose, throughput, packet delivery ratio decreased, data drop rate and End to End delay are increased compared with the 10 Drones case.

Table 4 The results of 20 Drones in the Network.

Parameter for 20 drones	Number of Captured Packets Of 20 drones	Packets without Interference	Packet Losses	Mean Power Consumption
Summation	1410	1015	395	54.8 %
Average	70.5	50.75	19.75	/
Throughput	4.7 bps = 0.5875 Bps			
PDR	Packet Delivery Ratio (PDR) = 0.719 Packets/Sec			
Data Drop Rate	0.2801 bps			
End to End Delay Time in Seconds	8.510 s			

Also, the log file from the proposed system showed in the Figure 3. 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.

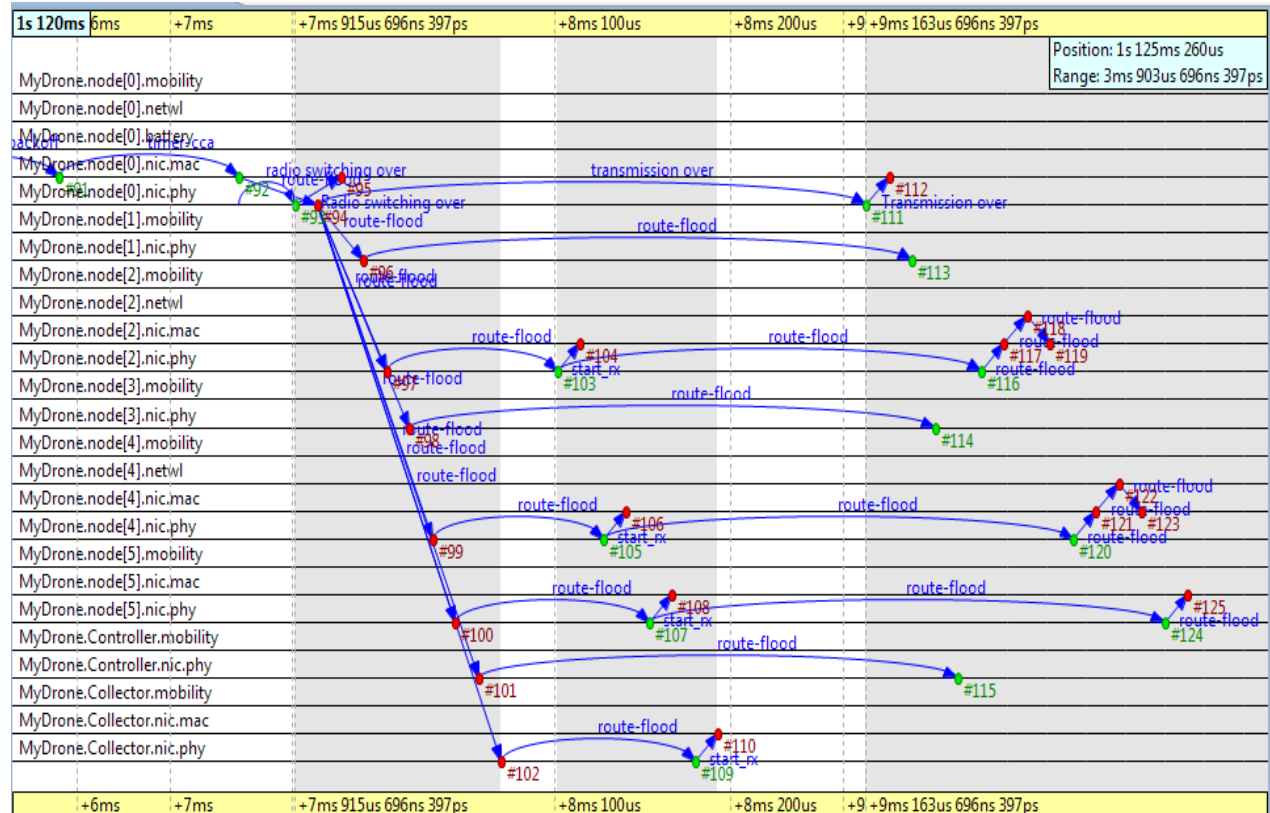


Figure 3 Log File of the proposed system

Conclusion

This paper highlights an overall study on the design and implementation of drone networks by using SDN and their service, and applications. 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. 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. The simulation results show the throughput, Packet Delivery Ratio (PDR) of network traffic decrease with an increase in the number of Drone nodes. As well as, the number of lost packets, the Data Drop Rate increase with an increase in the number of Drone nodes. 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 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.

References

- Alshamrani, A., Guha, S., Pisharody, S., Chowdhary, A., & Huang, D. (2018). Fault tolerant controller placement in distributed SDN environments. *In 2018 IEEE International Conference on Communications (ICC)*, 1-7.
- Singhal, C., & Rahul, K. (2019). Efficient QoS provisioning using SDN for end-to-end data delivery in UAV assisted network. *In 2019 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, 1-6.
- De Bruin, A., & Booyesen, T. (2015). Drone-based traffic flow estimation and tracking using computer vision: transportation engineering. *Civil Engineering= Siviele Ingenieurswese*, 2015(8), 48-50.
- Haleplidis, E., Pentikousis, K., Denazis, S., Salim, J.H., Meyer, D., & Koufopavlou, O. (2015). Software-defined networking (SDN): Layers and architecture terminology. RFC 7426.
- Elloumi, M., Dhaou, R., Escrig, B., Idoudi, H., & Saidane, L.A. (2018). Monitoring road traffic with a UAV-based system. *In 2018 IEEE Wireless Communications and Networking Conference (WCNC)*, 1-6.
- Erdelj, M., Król, M., & Natalizio, E. (2017). Wireless sensor networks and multi-UAV systems for natural disaster management. *Computer Networks*, 124, 72-86.
- Euchi, J. (2021). Do drones have a realistic place in a pandemic fight for delivering medical supplies in healthcare systems problems? *Chinese Journal of Aeronautics*, 182-190.
- Secinti, G., Darian, P.B., Canberk, B., & Chowdhury, K.R. (2018). SDNs in the sky: Robust end-to-end connectivity for aerial vehicular networks. *IEEE Communications Magazine*, 56(1), 16-21.
- Karaduman, M., Çınar, A., & Eren, H. (2019). UAV traffic patrolling via road detection and tracking in anonymous aerial video frames. *Journal of Intelligent & Robotic Systems*, 95(2), 675-690.
- Kaur, N., Aulakh, I.K., & Vig, R. (2016). Analysis of spread spectrum techniques in cognitive radio networks. *International Journal of Applied Engineering Research*, 11(8), 5641-5645.
- Khan, M.F., Felemban, E.A., Qaisar, S., & Ali, S. (2013). Performance analysis on packet delivery ratio and end-to-end delay of different network topologies in wireless sensor networks (WSNs). *In 2013 IEEE 9th International Conference on Mobile Ad-hoc and Sensor Networks*, 324-329.
- Khan, M.S., Gul, N., Kim, J., Qureshi, I.M., & Kim, S.M. (2020). A Genetic Algorithm-Based Soft Decision Fusion Scheme in Cognitive IoT Networks with Malicious Users. *Wireless Communications and Mobile Computing*, 2020.
- Kumar, A., Krishnamurthi, R., Nayyar, A., Luhach, A.K., Khan, M.S., & Singh, A. (2021). A novel Software-Defined Drone Network (SDDN)-based collision avoidance strategies for on-road traffic monitoring and management. *Vehicular Communications*, 28, 100313.

- Liu, P., Chen, A.Y., Huang, Y.N., Han, J.Y., Lai, J.S., Kang, S.C., & Tsai, M.H. (2014). A review of rotorcraft unmanned aerial vehicle (UAV) developments and applications in civil engineering. *Smart Structures and Systems*, 13(6), 1065-1094.
- Bari, M.F., Roy, A.R., Chowdhury, S.R., Zhang, Q., Zhani, M.F., Ahmed, R., & Boutaba, R. (2013). Dynamic controller provisioning in software defined networks. *In Proceedings of the 9th International Conference on Network and Service Management (CNSM 2013)*, 18-25.
- Tanha, M., Sajjadi, D., Ruby, R., & Pan, J. (2018). Capacity-aware and delay-guaranteed resilient controller placement for software-defined WANs. *IEEE Transactions on Network and Service Management*, 15(3), 991-1005.
- Motlagh, N.H., Bagaa, M., & Taleb, T. (2017). UAV-based IoT platform: A crowd surveillance use case. *IEEE Communications Magazine*, 55(2), 128-134.
- Rahman, S., Kim, G.H., Cho, Y.Z., & Khan, A. (2018). Positioning of UAVs for throughput maximization in software-defined disaster area UAV communication networks. *Journal of Communications and Networks*, 20(5), 452-463.
- Vashisht, S., Jain, S., & Mann, R.S. (2019). Software Defined UAV-Based Location Aware Deployment Scheme for Optimal Wireless Coverage. *In 2019 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing*, 907-912.
- Zhang, X., Wang, H., & Zhao, H. (2018). An SDN framework for UAV backbone network towards knowledge centric networking. *In IEEE INFOCOM 2018-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 456-461.
- Yanmaz, E., Yahyanejad, S., Rinner, B., Hellwagner, H., & Bettstetter, C. (2018). Drone networks: Communications, coordination, and sensing. *Ad Hoc Networks*, 1-15.
- Yuan, Z., Huang, X., Sun, L., & Jin, J. (2016). Software defined mobile sensor network for micro UAV swarm. *In 2016 IEEE International Conference on Control and Robotics Engineering (ICCRE)*, 1-4.
- Zhang, X., Wang, H., & Zhao, H. (2018). An SDN framework for UAV backbone network towards knowledge centric networking. *In IEEE INFOCOM 2018-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 456-461.