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MÁSTER EN INGENIERÍA EN TECNOLOGÍAS DE TELECOMUNICACIÓN

TRABAJO FIN DE MASTER

Networking connectivity through Drones using dynamic wireless Software Defined Networks

Autor
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Madrid
2022

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Life is about chances and opportunities, and how you use them.

Conectividad de red con drones usando redes definidas por software dinámicas e inalámbricas

Autor: Álvaro del Águila Martos
Directora: Dr. Janise McNair

Palabras clave: Dron, Starlink, Redes Inalámbricas, SDN, ONOS, Mininet-WiFi, QoS

Resumen

Este proyecto propone el uso de drones y SDN para dar conexiones de red inalámbricas a áreas que estén fuera de alcance sin acceso a internet. Este proyecto proporciona una selección de hardware para poder proveer Wi-Fi con drones. Simulaciones con Mininet-WiFi y el controlador de ONOS han sido realizadas para demostrar la veracidad de este proyecto.

Introducción

Los drones son una de las tecnologías más disruptivas creadas en la última década. Las posibilidades de uso que se les puede dar son mucho más que simplemente tratarse de un objeto volador controlado por remoto, y acabamos de comenzar a explorar sólo la superficie de sus usos y cómo de beneficiosos serían para el mundo actual.

Las redes definidas por software (SDN) [1] son un concepto revolucionario que ha ido ganando peso, separando el plano de control del plano de datos, permitiendo centralizar la red con un controlador, el cual es software construido con aplicaiones escritas en código de alto nivel, encargándose de las tablas de enrutamiento, los protocolos y los algoritmos encargados de la selección del camino a seguir del plano de control, dejando únicamente la función del plano de datos a los Puntos de Acceso de la red, reduciendo el uso de hardware en la red.

Este proyecto busca combinar estas dos tecnologías tan impactantes y todos sus beneficios para dar conectividad y capacidades de red a áreas fuera de alcance, teniendo una estación base como el controlador SDN, y usando los drones como Puntos de Acceso (AP), controlados por la estación base, creando una red móvil dinámica de malla que será de gran utilidad para áreas fuera de alcance como en áreas rurales o en emergencias como accidentes, áreas militares, o pérdidas de electricidad.

En este proyecto se hicieron simulaciones usando el controlador de ONOS y Mininet-WiFi, y distintas opciones de hardware propuestas para poder dar vida a este proyecto. Los drones serán parte del futuro de las telecomunicaiones, pudiendo ser los puntos de acceso móbiles automatizados perfectos, beneficiándose de la carácterística de la necesidad de menos hardware a través de las redes definidas por software, creando redes dinámicas para cualquier tipo de topología y escenario.

Un ejemplo de cómo sería la topología se puede ver en la Figura 1, en la que el controlador mueve automáticamente los drones sobre el área deseada, con drones de repuesto estacionados en la estación base para sustituir a los drones que están operando cuando desciendan sus niveles de batería, permitiéndoles cargar su batería en la estación base mientras que los nuevos drones operando en la red se mueven por el área, realizando un ciclo de flujo constante para poder dar disponibilidad constante de la red.

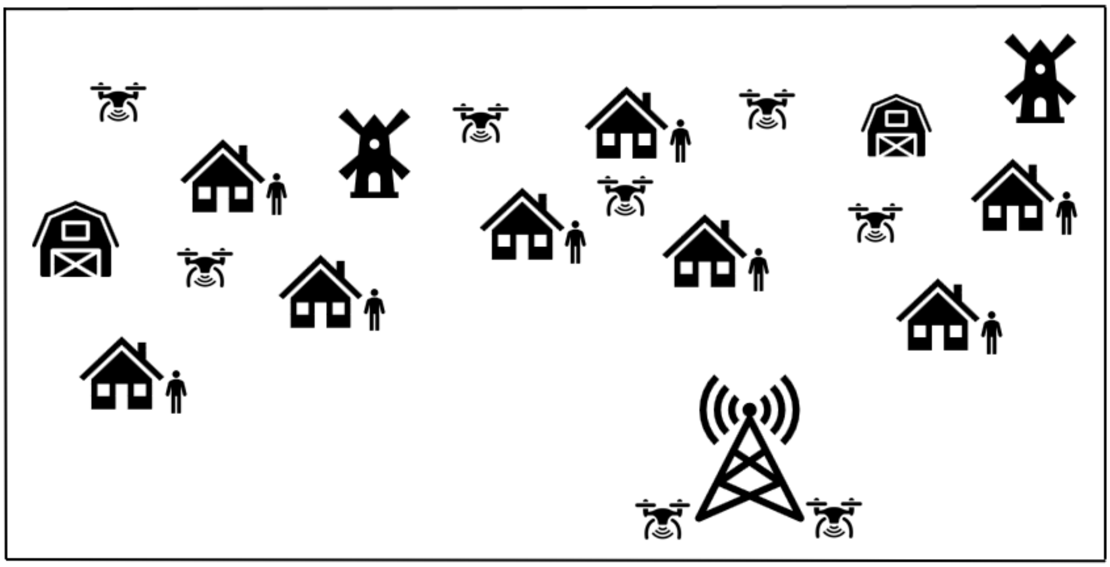

Figure 1: Ejemplo de topología.

Descripción del sistema

Todos los experimentos se realizaron en una Máquina Virtual de Ubuntu, con 8GB de RAM y 2 CPUs, en un ordenador con 16GB of RAM y un Intel(R)Core(TM)i7-3520M CPU @ 2.90GHz.

Los programas usados fueron Mininet con su extensión Mininet-WiFi [2] para crear una topología dinámica con código Python, ONOS [3] para establecer el controlador con aplicaciones escritas en código Java, y Wireshark para capturar los paquetes y evaluar los datos obtenidos.

Para ejecutar los experimentos, primero se inicializa el controlador de ONOS para cargar después sus aplicaciones. Después, una topología inalámbrica y dinámica fue creada virtualmente usando Mininet-WiFi, que permita conectar los Puntos de Acceso al controlador. El comando "pingall" se ejecuta, haciendo que los hosts virtualizados hagan ping al otro. Se compararon los resultados de las distintas aplicaciones, para seleccionar las mejores para el programador. Después, el código se mejoró para ser más eficiente energéticamente para hacer que la batería de los drones durara más.

Resultados

La aplicación que mostró los mejores resultados y que fue seleccionada es la aplicación de Reactive Forwarding, que establece la ruta de cada paquete según la demanda, cuando los paquetes se empiezan a enviar, funcionando de forma reactiva. Este comportamiento es ideal para las redes dinámicas como la propuesta en este proyecto. La aplicación de Reactive Forwarding después fue modificada para seleccionar el camino más corto de los posibles, entre los puntos de acceso, usando un puerto distinto al usado previamente, para evitar usar el mismo dron en la red, haciendo que la batería de los drones dure más en conjunto.

Los experimentos se realizaron haciendo pingall entre los hosts, lo que enviaría un paquete de ping de cada host al resto de host, mostrando la conectividad entre todos los hosts, permitiendo ver el rendimiento de la red de drones.

En el mejor escenario posible, en el que los drones y los host eran estáticos y podían alcanzarse del uno al otro, todos los paquetes enviados fueron recibidos, teniendo una red completamente operative. Sin embargo, ese no es un escenario realista, ya que los drones y los hosts estarían moviéndose constantemente por el área de la red.

Lo que ha sido estudiado es cómo la red y el controlador se comportarían dependiendo del número de drones en la red, cuando cada elemento de la red se estaría moviendo constantemente, como una situación más extrema, con un número medio de paquetes ping enviados de 1560.

En la Figura 2, se puede observar cómo cuantos más drones haya en la red, peor es la calidad de la red, incrementando el tiempo máximo para crear el camino por el controlador, e incrementando el número de paquetes perdidos.

Los paquetes por segundo en la red se pueden ver en la Figura 3, con el uso de Wireshark, observando un número mayor de paquetes estáticos en el gráfico inferior, que representa a la red con 14 drones. Esto es consecuencia de que el controlador tiene que lidiar con más puntos de acceso y la información que le tienen que enviar al controlador para que pueda elegir entre los posibles caminos, la mejor opción. También en este se observa menos picos de paquetes, que está

# of drones	Longest time to create a path	% of packages lost
9	1 ms	-
14	3 ms	+21%
20	41 ms	+23%

Figure 2: Comparación de las propiedades de la red en función del número de drones.

relacionado con enviar menos información de host a host. Por otro lado, en el gráfico superior, que tiene 9 drones, como hay menos puntos de acceso con los que tratar, hay menos información constante sobre los drones que el controlador tiene que procesar, y hay más picos de información enviada entre los hosts.

El controlador se satura con demasiados puntos de acceso en estas situaciones extremas, mostrando que un estudio de la red, su área, topología y usuarios se debe hacer para que el número óptimo de drones se pueda desplegar para tener el mejor rendimiento posible de la red. Estas simulaciones muestran que este proyecto puede ser eficiente y se puede trasladar a la realidad, teniendo en cuenta que la relación entre la topología de la red con el número de drones desplegados es importante para tener una calidad de servicio óptima en la red, con suficientes drones para lidiar con toda el área y sus hosts, y no saturar el área con drones, saturando el controlador.

La información sobre el hardware y los drones se ha dado en este proyecto con el motivo de encontrar la mejor selección para este proyecto. Los valores teóricos de los rangos de las tarjetas de WiFi y los SBCs no tienen por qué representar valores reales. La tarjeta SimpleLink Wi-Fi CC3235S dual launchPad sería la seleccionada para futuros experimentos. Una antena U.FL se puede añadir para tanto 2.4GHz como 5GHz a esta tarjeta [4]. El dron y la batería seleccionados para este proyecto son el ARRIS M900 4 axis Quadcopter frame kit [5] por la cantidad de vuelo que tendría equipado con la batería 6S 22.2V 25000mah. Los Xbees [6] funcionarán para conectar los drones entre ellos y crear la red.

Mantener los drones en el aire en periodos largos de tiempo es crucial para poder hacer realidad este enfoque de conexión. Tiempos de vuelo elevados requieren mucha energía, y en muchas ocasiones, los drones vienen equipados con baterías que no pueden mantener esta operación. Una evaluación del consumo de enería es realizado en este proyecto también.

Se pueden usar como alternativa cables de electricidad que conectarían el dron a

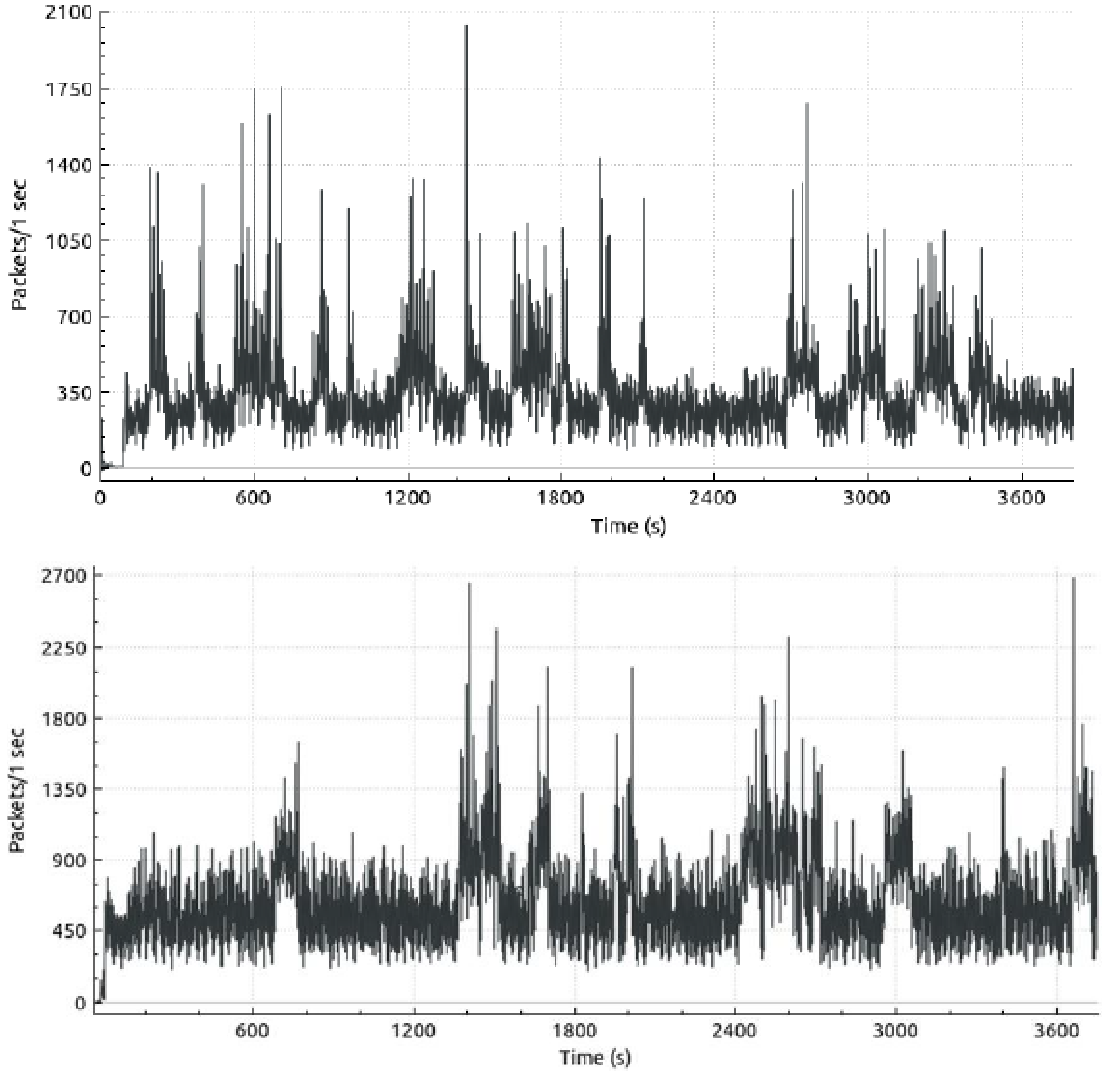

Figure 3: Flujo de paquetes en la red. El gráfico superior representa la red con 9 drones y el gráfico inferior representa la red con 14 drones.

un generador en tierra que daría un flujo de electricidad contínuo al dron en vuelo. Los cables tether, hechos con cable de calible 18, pueden conducir 400V de corriente DC. Con esto, los drones podrían estar en el aire periodos de tiempo largos aun con tiempo agresivo, dando una señal fuerte todo el tiempo. Hipotéticamente, en el caso de que el cable se desconecte, los drones estrían programados para cambiar a una batería de reserva para que aterricen automáticamente.

La estación base será hardware con una vista clara del cielo para poder acceder al internet por satélite de Starlink, llamado el kit de Starlink;, con una antena (plato de satélite) que recibirá y enviará las señales, un router Wi-Fi, un conector eléctrico, cabes, y un trípode para la antena. Esto proporcionará una red Wi-Fi en el area donde esté instalada. El siguiente paso será usar los drones como puntos de acceso para expandir la red, permitendo a todos los usuarios y dispositivos del area expandida conectarse a esta. [7]

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Key words: Drone, Starlink, Wireless Networking, SDN, ONOS, Mininet-WiFi, QoS

Abstract

This paper proposes the usage of drones and SDN to bring wireless networking capabilities to areas that are out of reach and that do not have internet access. This paper provides a selection of hardware that can be used to provide Wi-Fi through drones. Simulations to support this project were made using Mininet-WiFi and the ONOS controller.

Introduction

Drones are one of the most disruptive technologies created in the last decade. Their usage possibilities are many more than just a remote-controlled flying object, and we have just started to scrape the surface of their usages and how beneficial they could be in today's world.

Software defined networking (SDN) [1] is a revolutionary concept that has been gaining weight these past years, being able to separate the control plane from the data plane, and to centralize the network with a controller, which is software built with applications written on a high level code, being in charge of the routing tables, protocols and algorithms in the path selection of the control plane, leaving the data plane capabilities to the Access Points of the network, decreasing the use of hardware in a network.

This paper aims to combine this two impactful technologies and all their benefits to bring connectivity and networking capabilities to areas out of reach, having a central base station as the SDN controller, and using drones as mobile access points (APs), controlled by the central base station, creating a dynamic mobile mesh network that will be useful for areas out of reach such as rural areas or in emergencies such as accidents, deploy zones or power loss.

On this paper simulations were made using the ONOS controller and Mininet-WiFi, and different hardware is proposed to make this project come to life. Drones will be the part of the future of telecommunications, being the perfect automated mobile Access Points, benefiting from the need of less hardware through software defined networking, creating fast dynamic networks for any type of typologies and scenarios.

An example of how the topology would look is provided on the Figure 1, in which the controller moves automatically the drones around the desired area, with backup drones staying at the central base station to replace the operating drones when their battery is about to run out, letting them charge their battery at the central base station while the new ones are moving around the network, making a non-stop cycle loop to provide complete availability of the network.

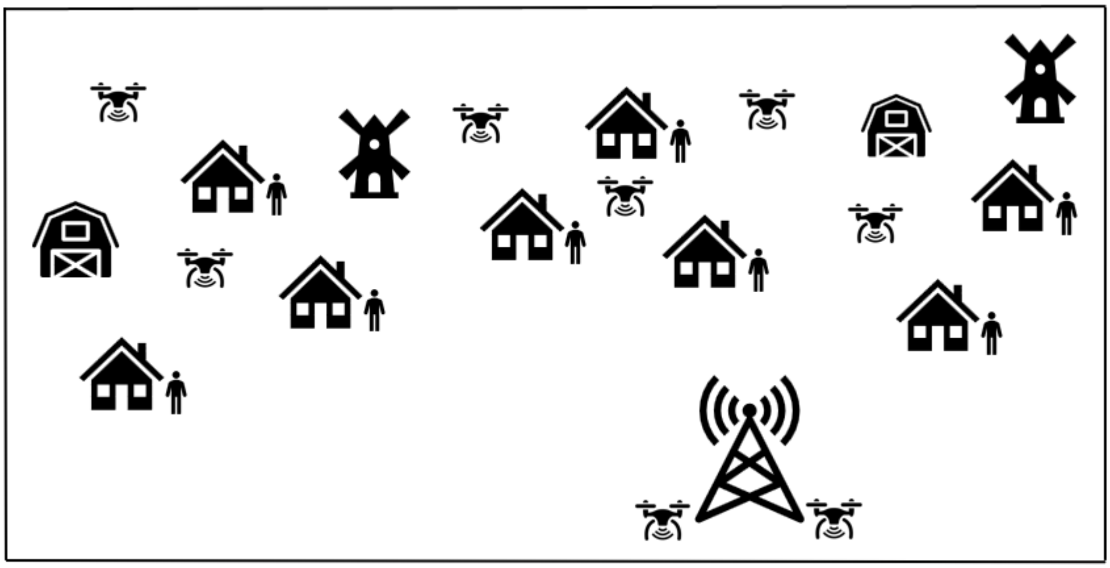

Figure 4: Topology case scenario.

System Description

All the experiments were run in an Ubuntu Virtual Machine with 8GB of RAM and 2 CPUs, in a computer with 16GB of RAM and an Intel(R)Core(TM)i7-3520M CPU @ 2.90GHz.

The programs used were Mininet with its Mininet-WiFi [2] extension to create the dynamic topology with python code, ONOS [3] to establish the controller with java code applications, and Wireshark to capture the packets and evaluate the data obtained.

To run the experiments, first the ONOS controller was initiated and had all its applications loaded. Then, a wireless dynamic topology was virtually created using Mininet-WiFi, that would connect its Access Points to the controller. The command ”pingall” was made, which would make every virtualized host do a ping to each other. Results with different applications were compared, to select the best configuration for the SDN controller. After that, the code was modified to make it more energy efficient to make the drones batterly last longer.

Results

The application that showed the best results and that was selected is the Reactive Forwarding app, which installs forwarding entries to the network switches on-demand after a sender starts transmitting packages. When a package is sent, the app handles the packet and configures the package accordingly. Because of its reactive behaviour on demand, it is ideal for dynamic networks like the one proposed in this project. The Reactive Forwarding app was then modified to select the shortest path from the possible ones, using a different port than the one previously used, to avoid using the same drone in the network, making their batteries last longer.

Tests were performed doing a pingall in between the hosts, which would send a ping package from each host to the rest of them, displaying the connectivity between all hosts, showing how well the drone network is performing. On the best case scenario, in which the drones and the hosts were static and they could all reach each other, all the packages sent were received, having a fully operational network. However, that is not a realistic approach, since the drones and the hosts would be moving around the area of the network.

What has been studied is how the network and the controller would behave depending on the number of drones in the network, when every element of the network would constantly moving, as a more extreme situation, with an average number of ping packages sent of 1560.

# of drones	Longest time to create a path	% of packages lost
9	1 ms	-
14	3 ms	+21%
20	41 ms	+23%

Figure 5: Comparison of network properties based on the number of drones

On Figure 5, it can be seen that the more drones in the network, the worse network quality there is, increasing the longest time to create a path by the controller, and increasing the number of packages lost from fewer drones to more drones.

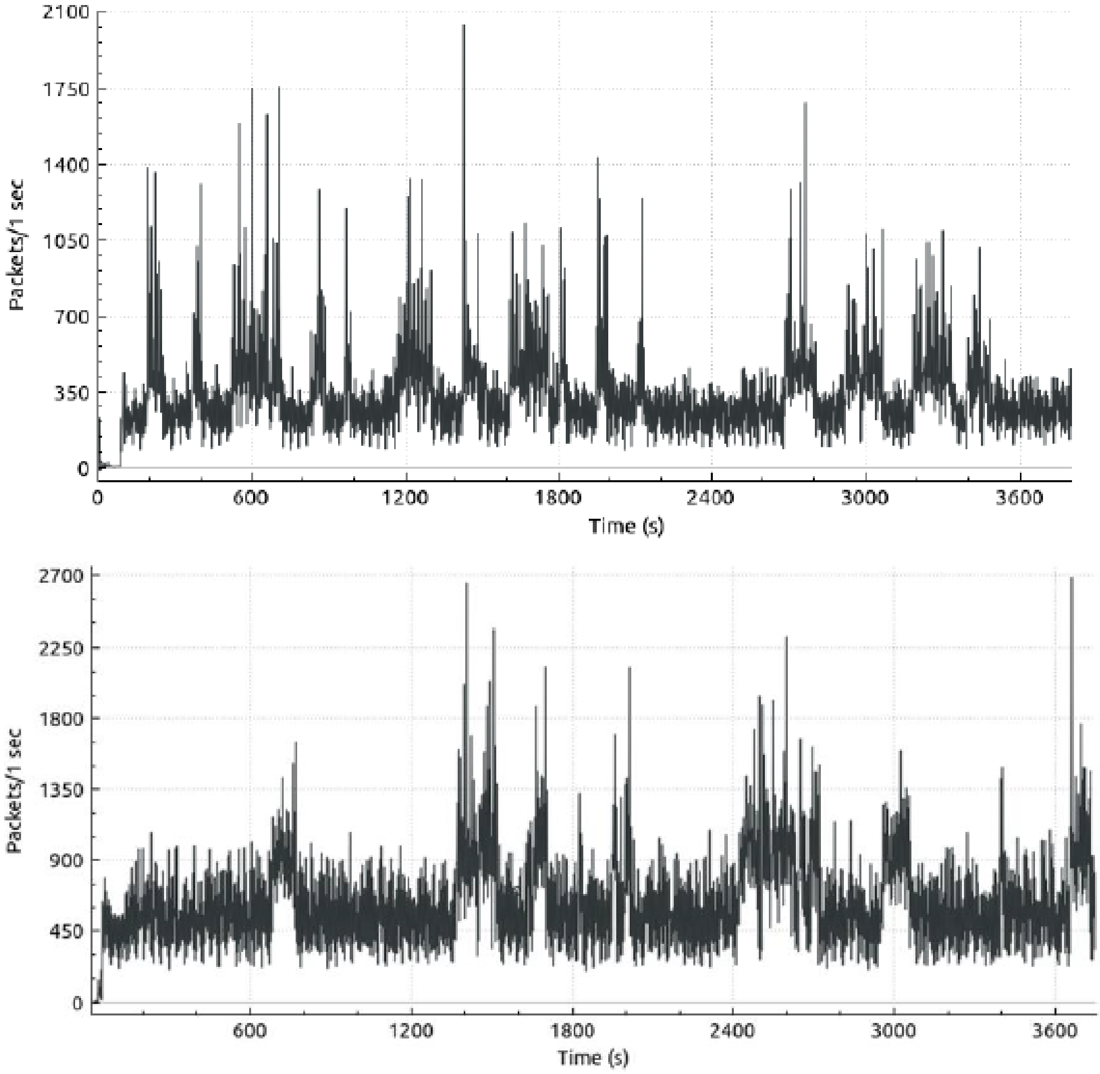

Figure 6: Packages flow in the network. The upper graph represents the network with 9 drones and the lower graph represents the network with 14 drones.

The packages per second in the network can be seen in Figure 6, with the usage of Wireshark, observing a more static number of packages on the lower graph, that has to do with the controller having to deal with more APs and information that they have to send to the controller in order for it to select from the possible paths the best option, and less peaks of packages that are related to sending information from host to host. On the other hand, on the upper graph, since there are less APs to deal with, less constant information about the APS has to be dealt by the controller, and more peaks of information sent between hosts can be seen.

The controller gets saturated with too many APs in this extreme situations, showing that a study of the network, its area, topology and users has to be done so that the optimal number of drones can be deployed to have the best possible performance of the network. This simulations show that this project could come to life and work efficiently, and that a relationship with the topology to work with and the number of drones deployed is important to have an optimal quality of service of the network, having enough drones to deal with the hole area and its hosts, and not overflow the area with drones, saturating the controller.

The information about hardware and drones will be given with the motive to find the best selection for this project. The theoretical values of Wi-Fi ranges of the boards and SBCs may not necessarily represent the real values. As for the selections of the boards, the SimpleLink Wi-Fi CC3235S dual launchPad would be selected to test. A U.FL Antenna can be added for both the 2.4GHz and 5GHz of this board [4]. The Drone and battery for this project would be the ARRIS M900 4 axis Quadcopter frame kit [5] because of the amount of flight time it possesses equipped with the 6S 22.2V 25000mah battery. A small battery can be added to power the boards or a PCB with a buck converter can be designed to power both the drone and the board with the same battery. The Xbees [6] will be great for connecting the drones together and making the network.

Keeping the drones in the air for long periods of time is crucial to making this approach to connectivity work. Long flight times require a lot of energy, and very often, drones are equipped with batteries that cannot sustain this operation. An evaluation of Energy Consumption is done in this project as well.

Power cord tethers, which connect the drone to a ground-based generator can supply continuous power to the drone in flight. The tethers are made of standard 18 gauge wire and can carry a 400V DC current. Using the tether, a drone can stay in the air for very long periods of time, even through harsh weather, providing a strong, reliable signal the whole time. Hypothetically, in the event of power loss, if the tether is disconnected for some reason, the drones can be programmed to switch to a backup battery and land automatically.

The base station will be ground hardware with a clear view of the sky to access Starlink's satellite internet, called the Starlink kit, with an antenna (satellite dish) that will get and send the signals, a Wi-Fi router, power supply, cables and a mounting tripod. That will provide a Wi-Fi network in the area where it is installed. The following step would be to use drones as Access Points to expand the network, letting all the users and devices in the expanded area get connected to it. [7]

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Chapter 1

Introduction

Drones are one of the most disruptive technologies created in the last decade. Their usage possibilities are many more than just a remote-controlled flying object, and we have just started to scrape the surface of their usages and how beneficial they could be in today's world.

Software defined networking (SDN) is a revolutionary concept that has been gaining weight these past years, being able to separate the control plane from the data plane, and to centralize the network with a controller, which is software built with applications written on a high level code, being in charge of the routing tables, protocols and algorithms in the path selection of the control plane, leaving the data plane capabilities to the Access Points of the network, decreasing the use of hardware in a network.

This paper aims to combine this two impactful technologies and all their benefits to bring connectivity and networking capabilities to areas out of reach, having a central station as the SDN controller, and using drones as mobile access points (APs), controlled by the central station, creating a dynamic mobile mesh network that will be useful for areas out of reach such as rural areas or in emergencies such as accidents, deploy zones or power loss.

On this paper simulations were made using the ONOS controller and Mininet-WiFi, and different hardware is proposed to make this project come to life. Drones will be the part of the future of telecommunications, being the perfect automated mobile Access Points, benefiting from the need of less hardware through software defined networking, creating fast dynamic networks for any type of typologies and scenarios.

An example of how the topology would look is provided on the Figure 1.1, in which the controller moves automatically the drones around the desired area, with backup drones staying at the central station to replace the operating drones when their battery is about to run out, letting them charge their battery at the central station while the new ones are moving around the network, making a non-stop cycle loop to provide complete availability of the network.

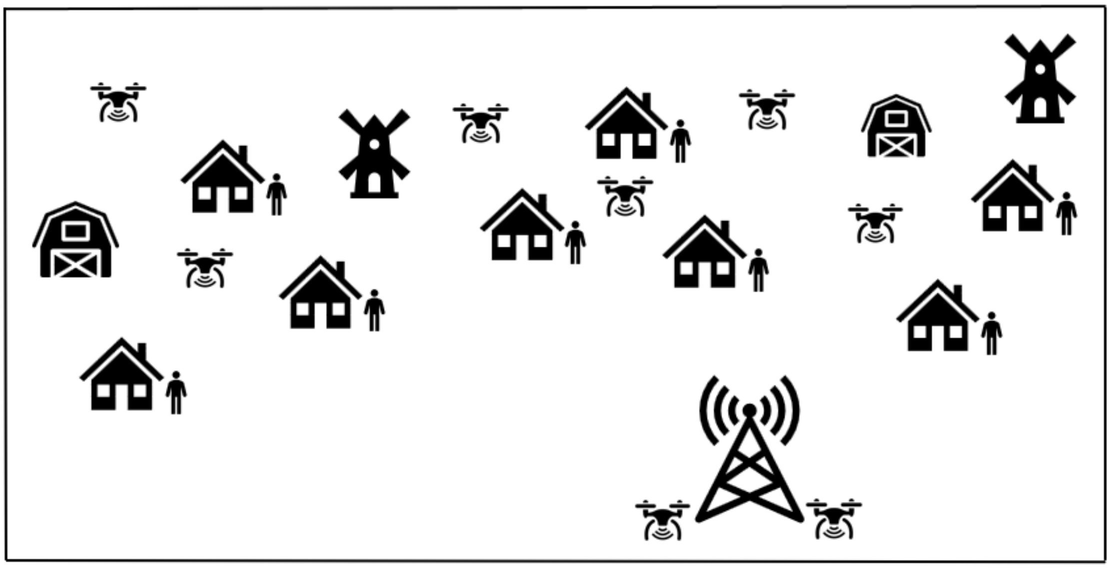

Figure 1.1: Topology case scenario.

1.1 Related work

1.1.1 WiFi Network on Drones

There is a great paper about Wi-Fi Network on Drones experiment published in 2016 ITU Kaleidoscope: ICTs for a Sustainable world (ITU WT) [1] which goes over precise measurements and equipment used to extend the capacity or coverage of wireless systems through the deployment of aerial communications networks [1]. They use an SBC called Galileo Generation 1 which is discontinued. This SBC was compatible with Linux and Arduino, and had Bluetooth, wireless and GSM connection. The full size mini PCIe slot allowed them to use standard mPCIe modules like WI-FI, Bluetooth and SIM card adapters for cellphones. Their project consisted of deploying the aerial network with both access point-based (AP) and the ad-hoc modes. They were able to successfully create an internet access point through the drone which was at a height of 10 and 20 meters of the ground.

1.1.2 Project Loon

This was a project by Google that shut down because it was not commercially viable. This project aimed to deliver wireless internet via flying balloons in the stratosphere. The Project Loon mission was to build a network of balloons to expand internet connectivity to under-covered areas and disaster zones. Loon's giant balloons were powered by solar panels and navigated using artificial intelligence that allowed them to ride high altitude wind currents. This Project can expand the possibilities for this Wi-Fi on drone's project. A hybrid project of a drone with some type of balloon could alleviate the flight time of the drones. Decreasing the number of drones and batteries to be deployed

1.1.3 Energy Saving Algorithms with ONOS

This paper [2] presents the concept of saving energy in the network elements by avoiding bottlenecks, managing the ports used, splitting their usage so that there were not just a few ports carrying all the weight of the network. This concept is very useful for this scenario, since one of the goals to have when dealing with drones is managing their battery making it last as long as possible.

1.1.4 Drone network for Tactical Applications

Networking in tactical applications introduces additional challenges that are not applicable to conventional network and its related infrastructure. They demand an efficient way to rapidly deploy the network infrastructure with minimal costs. Usage of drones for this application is suitable for the following reasons: they cost less when compared to a traditional cellular base station (such as an eNodeB) and they can be autonomously and quickly set-up at any location (even in unsafe territories). This paper [3] studies the usage of a controllable helium-based kite to quickly deploy broadband networks for serving the US army in Afghanistan. Radio antenna mounted on the kite communicated with a geostationary satellite and achieved upstream and downstream flows in the order of 5 and 20 Mbps respectively.

1.1.5 Analyzing performance of drone small cells

The authors of this paper [4] analyze the performance of drones to support cellular networks in overloaded and critical situations. The paper studies the impact of altitude on the downlink coverage for a single drone cell acting as a base station and shows that the optimal altitude for maximum coverage can be found by calculating the minimum value of path loss exponent, $L(\theta)$. Then, they study the optimal deployment for two drone cells in terms of altitude and distance between them. Mathematical results showed that for every configuration with two drones, there exists an optimal separation distance to minimize impact of interference on coverage performance. For example, a rectangular coverage area with dimensions 2000m and 700m had the highest coverage ratio of 0.78 when the perpendicular distance between the two drones was 1100m. Results obtained from this paper provide a foundation for more work with higher number of drone cells.

1.1.6 Opportunities and challenges of drones in wireless communication

This paper [5] talks about the promises and shortcomings of using drones to provide wireless connectivity compared to terrestrial communication infrastructure. Predominantly, UAV (Unmanned Aerial Vehicle) systems are more cost-effective and can be swiftly deployed which makes them suitable for limited-duration operations. They offer significant improvement in short-range line-of-sight (LoS) communication over broadband stations that cannot provide coverage in remote locations such as dense jungles and mountain regions. Drones can be maneuvered by varying altitude and location offering new possibilities of enhanced performance. Despite these benefits, UAVs in wireless network communication come with several design challenges. Flying drones often involve obtaining stringent security permissions from various agencies. They have to be secured from mid-flight collisions such as unforeseen obstacles or bird attacks. Also, if drones have to facilitate network connectivity over vast regions, a swarm of drones have to be designed carefully with high level of co-ordination to ensure reliability. Another major challenge is the power and payload constraints that drones offer. Low battery capacity often limits the flight time of many drones. To tackle these shortcomings, energy efficient designs and operations, such as reducing processing power consumption, reducing payload and body weight etc. are needed for maximum usage.

For enhancing performance, the authors present two techniques, namely, UAV-enabled mobile relaying and D2D-enhanced UAV information dissemination. In the first technique, the drone divides its operation between source and destination. During the first phase, the drone flies towards the source to find δ, which corresponds to maximum tolerable delay. The drone stores the source information in its local buffer and after time greater than δ, it flies towards the destination and relays the information from its buffer. The drone then returns to the initial position at the end of cycle when time equals 2δ. In the second technique, D2D protocol is used to provide benefits such as energy saving and lowering capacity requirement for drone wireless backhaul [6]. This technique employs a two-phase process for information dissemination. In the first phase, drones broadcast the same information packets to all ground nodes as it flies over them. Due to limited wireless connectivity, the ground nodes receive only a part of the transmitted packet. In the second phase, the ground nodes exchange the remaining portion of the packets by communicating with each other. This significantly reduces the number of drone re-transmissions thereby saving energy.

1.2 Objectives of the project

The objectives of this project are divided in the following ones:

- Ensure Quality of Service of the network.
- Find the optimal applications to use in the SDN controller through simulations.
- Optimal configuration of the drones' hardware.
- Optimal configuration of the base station's hardware.
- Selection of the network to get connected through the base station.
- Simulations to test possible network configurations in each different type of area.

1.3 Motivation

This is a project that combines two emerging disruptive technologies that could change the world to make it a better place. It is very exciting to be part of something that will be so big in the near future. This will change millions of people's lives, helping the ones who specially need it the most such as in warzone areas or where infrastructures cannot be installed due to geography or economic reasons

1.4 Definitions

This definitions have already been used in a previous project of mine, which will be cited here: [7]

- Quality of Service: The Quality of Service QoS are a set of requirements that must be met in order to have a proper network functionality and performance. There are different parameters that can measure the QoS of a network:
  - Packet loss: When packages are dropped and not received to its destination.
  - Latency: It is the time a packet takes to travel from the source to the destination. It should be as close to zero as possible.
  - Jitter: Congestion of the network, making the network slower.
  - Bandwidth: It is the capacity of a network's link to send the maximum amount of data from one point to another in a determined time frame.
  - Availability: Amount of time that the network is fully operating.
  - Resilience: Capacity to recover in case a network failure occurs.
- Switch: A hardware device that filters and forwards network packets.
- Access Point: Device that creates a wireless local area network, and transmits data, connected to the controller with cables.
- Host: Device connected to the network that can send and receive information.
- Link: A connection between two network devices.
- Virtual Machine (VM): A virtual machine (VM) is a virtual environment that functions as a virtual computer system with its own CPU, memory, network interface, and storage, created on a physical hardware system (located off- or on-premises). Software called a hypervisor separates the machine's resources from the hardware and provisions them appropriately so they can be used by the VM.
- Hardware: Every physical electronic device.
- Software: Programs running on the software. For example an operating system like Windows.

- Ping: It is a basic tool that allows the user to know if an IP address exists and can accept requests. Ping works by sending an Internet Control Message Protocol (ICMP) Echo Request to a specified host on the network and waiting for a reply. It can be used to test connectivity and determine response time.

1.5 Scope of work

First, a research and selection of the most optimal hardware parts to use for the drones would be needed to be done.

The central base station and its hardware, and the network to get connected with it, must be studied. This is a key part in order for the drones to get connected to a working network that can access the internet.

The simulation environment must be built, followed by making tests regarding the SDN controller applications to use, and the optimal number of drones to have in each specific area.

1.6 Resources

All the experiments were run in an Ubuntu 18.04 Virtual Machine with 8GB of RAM and 2CPUs, in a computer with 16GB of RAM and an Intel(R)Core(TM)i7-3520M CPU @ 2.90GHz.

The programs used were Mininet with its Mininet-WiFi extension to create the dynamic topology, ONOS to establish the controller and its GUI to get network information, Wireshark; a network packet analyzer, to capture the packets and evaluate the data obtained.

Chapter 2

Hardware

2.1 LaunchPad

A Single Board Computer are computers on a single chip, unlike traditional computers where there is a mother board and separate peripherals needed to make the PC or Mac functional. These are usually more powerful than Launchpads which are inexpensive TI prototyping tool that provides on-board emulation for programming and debugging. These launchPads are getting better throughout the years and therefore there have been listed the ones that may be able to be used to avoid using SBC due to their higher power consumption.

The first selection will be the SimpleLink Wi-Fi CC3235S dual band launchpad a single chip security and wireless microcontroller which integrates a user application dedicated ARM cortex MCU and a network processor that runs 2.4GHz and 5GHz Wi-Fi internet, and security protocols [8]. This board is very popular to implement IOT projects and are great for making mesh networks which is what will be required. An interesting fact of this board is that an antenna can be added to increase its signal strength. Wi-Fi Tx power 2.4 GHz 16dBm at 1 DSSS, 5GHz 15.1 dBm at 6 OFMD. Wi-Fi RX sensitivity 2.4 GHz -94.5 dBm at 1 DSSS, 5GHz -89 dBm at 6 OFMD.

The next board is also by TI, CC3100MODBOOST SimpleLink. This board integrates protocols for Wi-Fi and internet which greatly minimize host software requirements [9]. Transfer power, 17dBm at 1 DSSS, 17.25 dBm at 11CCK and 13.5dBm at 54 OFDM. The RX sensitivity is -94.7dBm at 1 DSSS, -87 dBm at CCK and, -73 dBm at 54 OFDM [9]. These boards are great selections for this project.

2.2 SBC

In case of more power required to drive our Wi-Fi network there is the option of using SBCs. Raspberry pi 4 would be an excellent choice due to the large selection of computer Wi-Fi cards that can be added, but due to its size it may limit the drone choices that could be had and may not be the most energy efficient. Instead, I a few competitors were selected which can have the require functionalities required to successfully drive our network.

Rock Pi X B4E32 can run windows 10 and it is a compact size Raspberry Pi for factor as well it includes 802.11 ac Wi-Fi and Bluetooth 4.2 to realize IoT projects with and onboard antenna and external support [10]. The size is 85mm x 54mm which is not too big of a footprint. This board also provides GbE LAN with power over the Ethernet (PoE) support.

Another board is the Rock PI 4 model C which is from the same family as the previous board. It also provides 802.11 ac Wi-Fi and Bluetooth 5.0 with on board antenna. GbE LAN with PoE support and is the same dimension 85mm x 54 mm. These two boards should be able to handle the network range but like stated before if more power is needed, the Raspberry Pi would be the next candidate because it allows for PCIE 2x1 socket which allows for broader use of stronger antennas such as EDUP PCIe Wi-Fi 6 card 2x 6dBi high-gain antennas [11].

2.3 Xbee

It cannot be forgotten about how the drones will be communicating to each other during the fly time. Xbees can be used to take care of this matter. Xbees are a great way to control and connect to networks and this would not interfere with the Wi-Fi network. These modules are easy to configure and very small in size. The Digi Xbee DigiMesh 2.4 has multiple antenna options [12]. Outdoor Rf Line-of-sight range up to 2 miles(3.2Km) with high gain antennas and they also provide with the cloud software to implement any project.

2.4 Drones

The number of drones deployed to provide Wi-Fi depends on the area required to be covered with the network as well as the distance between drones where the Wi-Fi network can still be connected form each other. Wi-Fi can have a range of around 300 feet. Another aspect that was kept in mind when selecting the drone was the flight time of the drone. Typical flight time for most high-quality drones is about 20 minutes which is not a very long time. Also, drones have a payload limit they can carry and therefore this payload can decrease the flight time as well. The Size must be big enough to carry the SBCs or LaunchPads and the battery to power it. The following drones are great candidates to choose a model from and are great for projects like these because the software and hardware can be added as required.

The ARRIS M900 4 axis Quadcopter Frame kit good for long Flight time [13]. Compatible with 6S 22.2v 12000mah to 25000mah. The flight time is about 60 minutes with 6.7Kg takeoff weight. And 30 minutes with 9.7Kg takeoff weight.

The next drone is a ZD550 pro 550mm 4 Axis carbon fiber umbrella folding quadcopter combo with motors ESC propeller [14]. Has a flying time of 20 minutes with 4s 10000mah battery.

The third drone is the ARRIS M700 umbrella foldable carbon fiber hex copter frame [15] with most of the aspects of the previous drone.

Finally, there is the Tarot Peeper Long Flight Quadcopter Super Combo TL750S1 that can fly for around 47 minutes with a 6S 10000mah Lipo battery. There are plenty of powerful batteries on the market today which makes easy to select one to accommodate the desired needs.

2.5 Hardware selection

The information about hardware and drones was done with the motive to find the best selection for this project. The theoretical values of Wi-Fi ranges of the boards and SBCs may not necessarily represent the real values. As for the selections of the boards, the SimpleLink Wi-Fi CC3235S dual launchPad would be selected to test. A U.FL Antenna can be added for both the 2.4GHz and 5GHz of this board. The Drone and battery for this project would be the ARRIS M900 4 axis Quadcopter frame kit because of the amount of flight time it possesses equipped with the 6S 22.2V 25000mah battery. A small battery can be added to power the boards or a PCB with a buck converter can be designed to power both the drone and the board with the same battery. The Xbees will be great for connecting the drones together and make a network they are very easy to use.

2.6 Continuous power supply

Keeping the drones in the air for long periods of time is crucial to making this approach to connectivity work. Long flight times require a lot of energy, and very often, drones are equipped with batteries that cannot sustain this operation.

Power cord tethers, which connect the drone to a ground-based generator can supply continuous power to the drone in flight. The tethers are made of standard 18 gauge wire and can carry a 400V DC current. Using the tether, a drone can stay in the air for very long periods of time, even through harsh weather, providing a strong, reliable signal the whole time. Hypothetically, in the event of power loss, if the tether is disconnected for some reason, the drones can be programmed to switch to a backup battery and land automatically.

Chapter 3

Evaluation of Energy Consumption

Drones will gain more popularity as flying base stations in wireless communication. However, due to their limited on-board battery, the typical flight time is restricted to less than 1.5 hours. Therefore, it is very important to design energy efficient solutions when deploying drones. To maintain uninterruptible network connectivity in the coverage area, authors of [16] proposed swapping UAVs. Fully charged back-up drones are readily swapped as soon as the battery gets drained. Another less expensive solution is to replace the drained batteries with fully charged ones, to avoid waiting for the drained battery to be recharged. This method requires additional labor costs for manual replacement of the batteries.

When considering energy costs for replacing batteries or recharging them, we have to consider the costs involved in flying the drone to and from the charging station. Authors of [17] developed a mathematical model to calculate the time a drone can hover at a hotspot based on the battery capacity. Given, T_{se} denotes the time a drone can fly at a hotspot to provide cellular service and T_{tra} is the time required by the drone to travel to and from the nearest charging station, we can define them as follows:

$$\begin{aligned} T_{\mathrm{se}} =& \frac{B_{\max} - 2P_{\mathrm{m}}\frac{R_{\mathrm{s}}}{V}}{P_{\mathrm{s}}}, \\ T_{\mathrm{tra}} =& \frac{2R_{\mathrm{s}}}{V}, \end{aligned} \tag{1}$$

where B_{max} is the battery size, P_m is the power consumed during travelling, V is the velocity with which the drone travels and P_s is the power consumed when the drone is hovering at the center of the hotspot. P_s here accounts for both power required for data communication and propulsion. Distance between the center of the hotspot and the nearest charging station is denoted by R_s. The value of P_s is assumed to be fixed whereas P_m is denoted as follows:

$$P_{\mathrm{m}} = P_0 \left(1 + \frac{3V^2}{U_{\mathrm{tip}}^2}\right) + \frac{P_{\mathrm{i}} v_0}{V} + \frac{1}{2} d_0 \rho s A V^3, \tag{2}$$

where U_{tip}^2 is the tip speed of the rotor blade, v_0 is the mean rotor induced velocity in hover, ρ is the air density, A is the rotor disc area, d_0 is fuselage drag ratio, V is the velocity of the UAV, and P_0 and P_i represent the UAV's blade profile power and induced power in hovering status, respectively.

The energy consumed by UAV for travelling between the hotspot and charging station is

$$\begin{aligned} E_t = & \frac{R_{\mathrm{s}}}{V} P_{\mathrm{m}} \\ = & \frac{R_{\mathrm{s}}}{V} \left(P_0 \left(1 + \frac{3V^2}{U_{\mathrm{tip}}^2}\right) + \frac{P_{\mathrm{i}} v_0}{V} + \frac{1}{2} d_0 \rho s A V^3 \right). \end{aligned} \tag{3}$$

Chapter 4

Starlink: The base station

One of SpaceX's biggest innovations and projects is called Starlink and it consists of bringing internet access all around the world at a reduced price, giving better access and availability everywhere but especially in places where internet access was not available before.

It involves beaming internet data, but via radio signals through the vacuum of space. Ground stations on the Earth broadcast the signals to satellites in orbit, which can then relay the data back to users on Earth. To make this possible, thousands of low orbit satellites would be put in space above the Earth. The Starlink constellation could have as many as 42.000 satellites, and they would be orbiting 350 miles / 550 Km above Earth. Starlink uses SDN as well in between the satellites, in order to construct the paths to follow to send the information.

Those satellites will be able to transmit fast internet signals down to Earth, with an original download internet speed of 1Gbps, and a latency around 30ms [18]. The previously called central station will be ground hardware with a clear view of the sky will have to be installed in order to access Starlink's internet, called the Starlink kit, with an antenna (satellite dish) that will get and send the signals, a Wi-Fi router, power supply, cables and a mounting tripod. In this scenario, using a cloud SDN controller would not require to add more hardware to the equation.

That will provide a Wi-Fi network in the area where it is installed. The following step would be to use drones as Access Points to expand the network, letting all the users and devices in the expanded area get connected to it, as shown on Fig 1.1.

Chapter 5

The software defined network

5.1 Defining SDN

As an emerging networking architecture, Software Defined Networking (SDN) is established as a promising concept for our future. It is an efficient networking technology that supports the dynamic nature functions of our future networks with the crucial aspect of simplifying hardware through software, with many benefits such as lowering costs, and being the perfect network configuration when using drones as access points [19].

The main characteristics that differentiate SDN from any other network layer architectures are:

- Differentiation and separation of the control plane and the data plane of the switching hardware.
- Using software for the control plane functions, reducing hardware usage and requirements. That software is known as a controller, which is centralized and has a complete view of the network.
- Open interfaces between the controllers and the devices located in the data plane, which in this case will be the drones.
- Customization of the controller through applications that can be programmed by any external source or user; which will be essential when adapting the controller to the network.

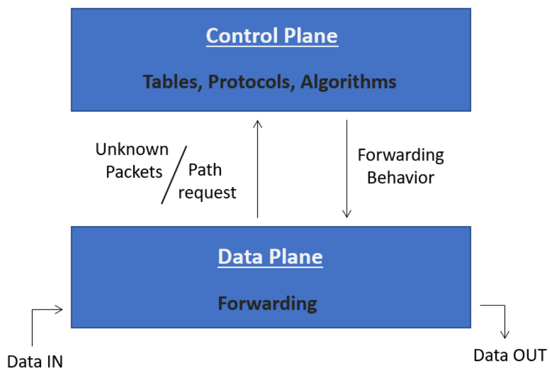

Figure 5.1: Control plane and data plane schemes regarding SDN

5.2 The controller

When talking about the controller to use, different options can be considered:

- Ericsson controller or similar, which are cloud based SDN controllers, with the benefit of configuring the controller apps and accessing all the information in real time from anywhere with a connection, and the negative side of paying for accessing its service, and being dependent on the connectivity, loosing the control of the network topology when there is no connection.
- ONOS controller, which will be discussed in more detail later on this paper as an open source controller, with the benefit of being free, but with the downside of having to physically and manually install it and its applications, monitoring it and the network in person and not on remote.

Chapter 6

Simulations

6.1 Environment installation guide

There has been a complete and detailed guide on how to install and configure this environment to be able to perform the simulations done in this project. It can be found in my previous project [7] There is also a more detailed explanation of what SDN, the ONOS controller, and Mininet-WiFi are and how they work.

6.2 Mininet-WiFi

Mininet is a SDN network emulator that simulates virtual hosts, switches, links and controllers, that run Linux network software [20].

Mininet-WiFi is an extension that adds WiFi stations and Access Points (AP) based on wireless Linux drivers, which perfectly suits the wireless dynamic SDN network needs that are demanded for the simulations of this proposal, using mobile APs as drones. It supports OpenFlow, and it can get connected to the ONOS controller, which is the controller used for this project proposal.

Mininet-WiFi can run scripts programmed on Python, which gives freedom to create different topologies for different tests. Mininet-WiFi gives the tools to create your custom dynamic SDN network, adding as many hosts and APs as needed, with a defined range, and mobility with different speeds and paths that can be programmed. That can provide the perfect set up since different scenarios can be experienced such as hosts getting out of reach, or conflicts of hosts being in range with more than one AP. Tests with static hosts and APs have been made as the perfect case scenario, and also scenarios with moving drones (APs) and hosts were made in order to study how the network would behave in more extreme scenarios. The network simulated had an area of 1km x 1km, 40 hosts, and a different number of drones (APs) that will be tested, with a reliability of 120 meters, according to the data of the real hardware that would be used when building this project.

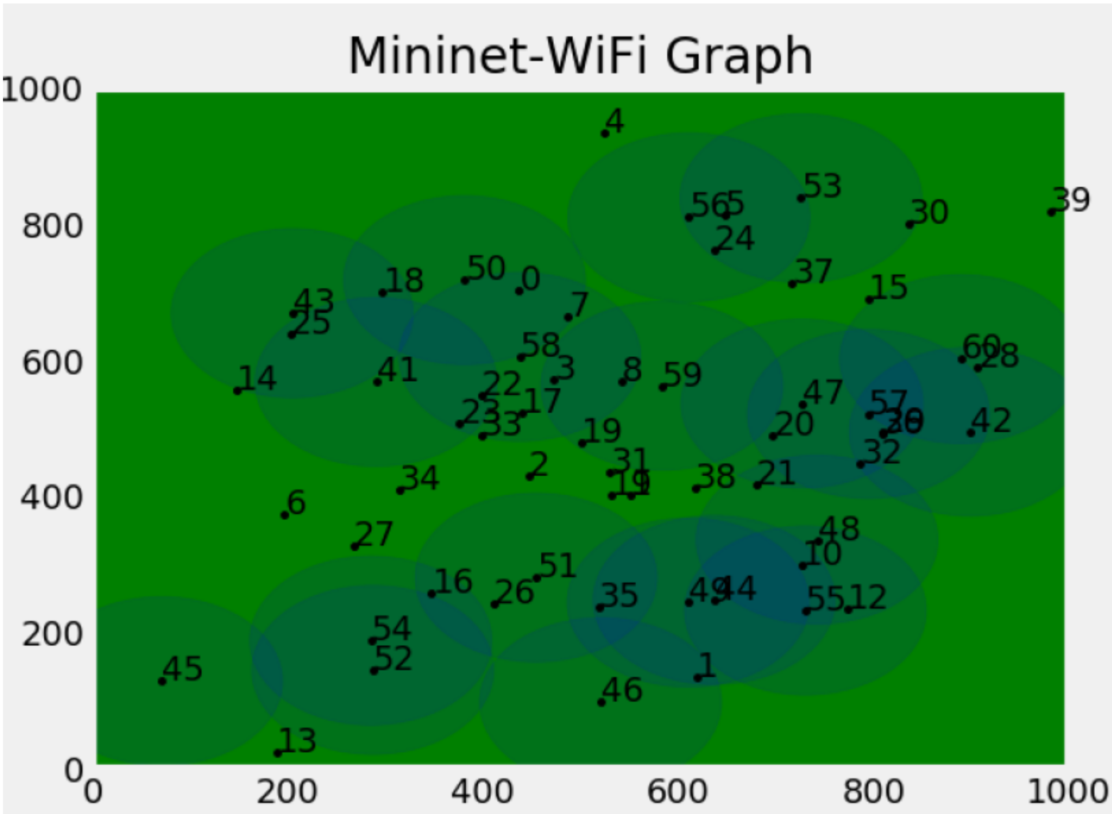

Figure 6.1: Example of a dynamic topology run in Mininet-WiFi, with 40 hosts and 20 drones (APs).

6.3 The ONOS controller

The controller used for this project proposal's simulations is the ONOS controller; which stands for Open Network Operating System [21].

As mentioned previously, the SDN controller is built with different applications written in Java code.
One of the most important ones is the OpenFlow protocol; which has a very important role in the controller, giving access to the forwarding plane of a network switch or router, and allowing the controller to determine the route of the packets across a network. It is layered on top of the Transmission Control Protocol (TCP) and establishes the use of the Transport Layer Security (TLS).

When considering the ONOS applications to use and the forwarding application, possible options that ONOS offered and that were evaluated were SDN IP, SDN Reactive Routing, Reactive Forwarding, Path Visualization and Segment Routing. They were tested individually and combined, finding out that by just having the Reactive Forwarding app, the best packages sent/received were obtained, having a simpler controller that would have to deal with less information and types of packages in the network, having a positive impact on the drones, dealing with less packages and having a longer battery life.

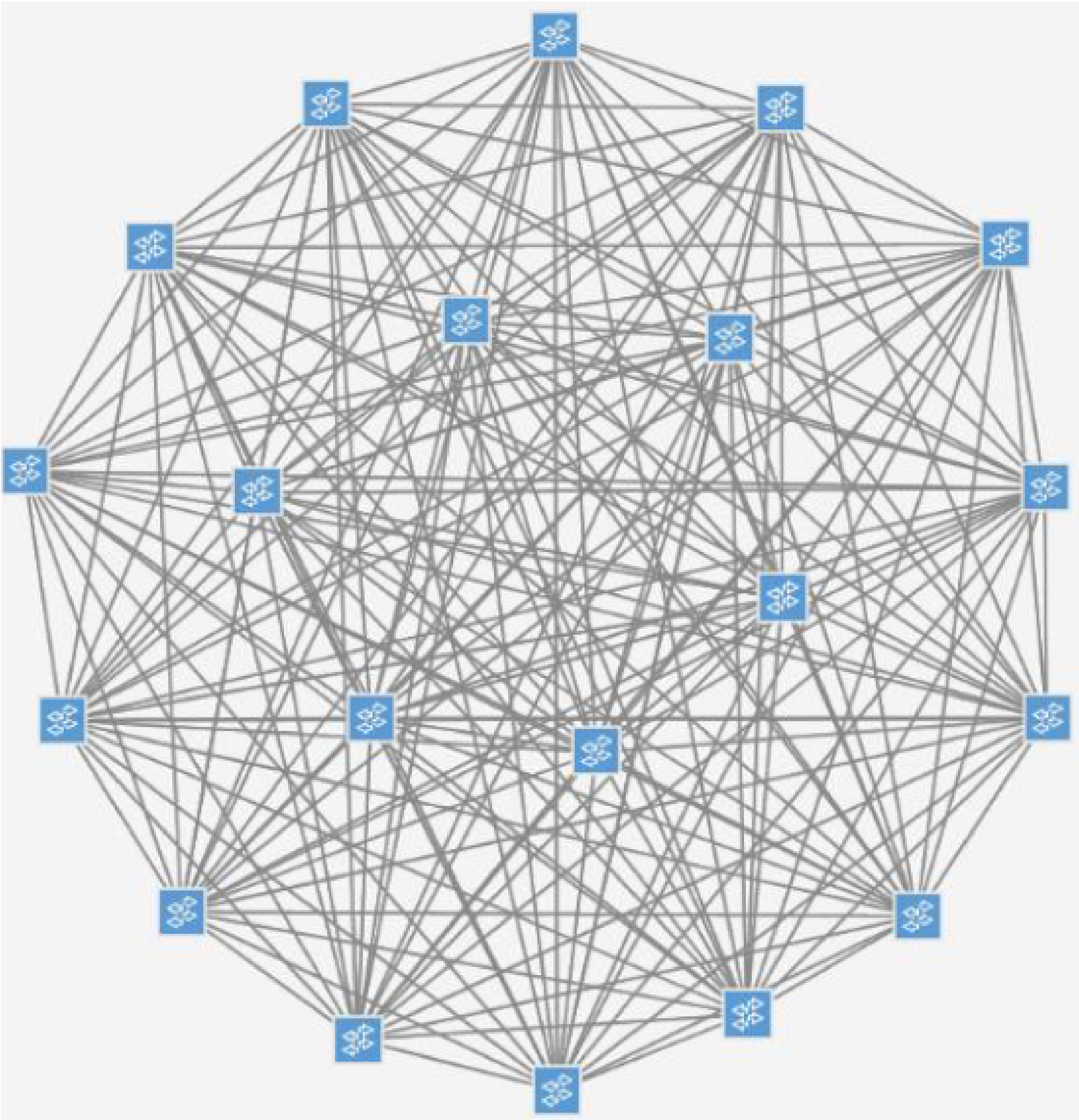

Figure 6.2: Representation of an example a dynamic mobile mesh network of 20 drones (APs) from the ONOS GUI

Based on the previous results, the selected forwarding app for the controller is the Reactive Forwarding app; which installs forwarding entries to the network switches on-demand after a sender starts transmitting packages. When a package is sent, the app handles the packet and configures the package accordingly. Because of its reactive behaviour on demand, it is ideal for dynamic networks like the one proposed in this paper.

Originally, the Reactive Forwarding app works choosing the first path available from the sender to the receiver, giving priority to the time to build the path, but for this project the application was modified to choose the paths based on the shortest paths in hops count, using the less drones possible, using the shortest path algorithm. Based on the related work section, the app was modified as well so it would not use the same path used previously, making those changes to not only focus on a few drones, giving them less use so they would have a longer battery life and a better network availability for the hosts.

```
/*
    private Path pickForwardPathIfPossible(Set<Path> paths,
   PortNumber notToPort) {
        for (Path path : paths) {
            if (!path.src().port().equals(notToPort)) {
                return path;
            }
        }
        return null;
    }
*/


    private Path pickForwardPathIfPossible(Set<Path> paths,
   PortNumber notToPort) {
        Path bestPath = null;
  for (Path path : paths) { //goes through all the paths
            if (!path.src().port().equals(notToPort)) {
    if((bestPath == null) || (path.cost()<=bestPath.cost()) && ((path
   !=oldPath) || (oldPath == null))){
      bestPath=path;
    }else if((bestPath == null) || (path.cost()<bestPath.cost()))
      bestPath=path;
            }
  }
  return bestPath;
    }
```

Listing 6.1: Original Java code in the commented upper part vs modified code in the lower section

6.4 Experimental Analysis

Tests were performed doing a pingall in between the hosts, which would send a ping package from each host to the rest of them, displaying the connectivity between all hosts, showing how well the drone network is performing. On the best case scenario, in which the drones and the hosts were static and they could all reach each other, all the packages sent were received, having a fully operational network. However, that is not a realistic approach, since the drones and the hosts would be moving around the area of the network.

What has been studied is how the network and the controller would behave depending on the number of drones in the network, when every element of the network would constantly moving, as a more extreme situation, with an average number of ping packages sent of 1560.

# of drones	Longest time to create a path	% of packages lost
9	1 ms	-
14	3 ms	+21%
20	41 ms	+23%

Figure 6.3: Comparison of network properties based on the number of drones

On Figure 6.3, it can be seen that the more drones in the network, the worse network quality there is, increasing the longest time to create a path by the controller, and increasing the number of packages lost from fewer drones to more drones.

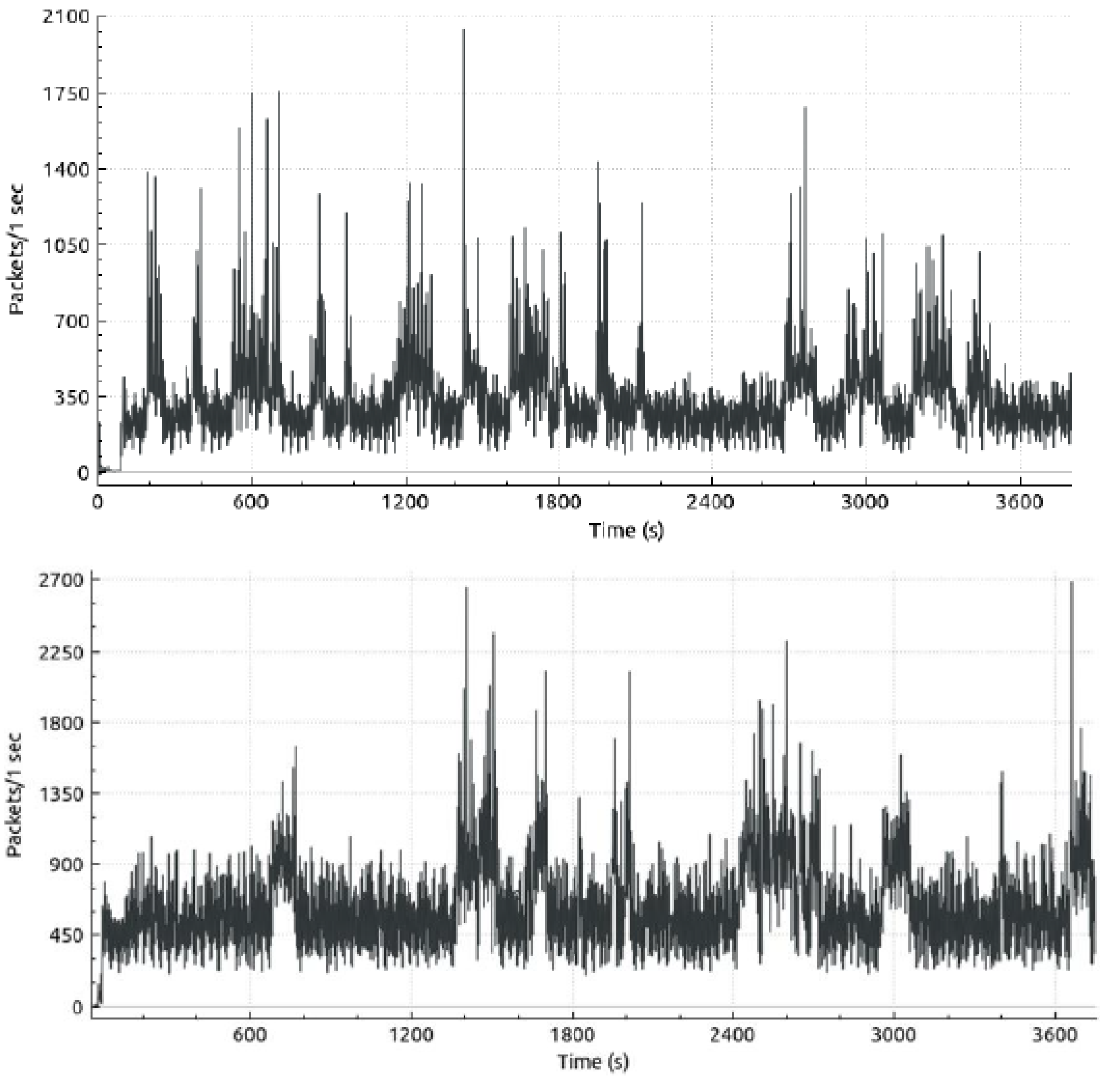

Figure 6.4: Packages flow in the network. The upper graph represents the network with 9 drones and the lower graph represents the network with 14 drones.

The packages per second in the network can be seen in Figure 6.4, with the usage of Wireshark, observing a more static number of packages on the lower graph, that has to do with the controller having to deal with more APs and information that they have to send to the controller in order for it to select from the possible paths the best option, and less peaks of packages that are related to sending information from host to host. On the other hand, on the upper graph, since there are less APs to deal with, less constant information about the APS has to be dealt by the controller, and more peaks of information sent between hosts can be seen.

The controller gets saturated with too many APs in this extreme situations, showing that a study of the network, its area, topology and users has to be done so that the optimal number of drones can be deployed to have the best possible performance of the network.

This simulations show that this project could come to life and work efficiently, and that a relationship with the topology to work with and the number of drones deployed is important to have an optimal quality of service of the network, having enough drones to deal with the hole area and its hosts, and not overflow the area with drones, saturating the controller.

Chapter 7

Future works

This paper is a proposal of a project that when fully finished, will benefit a large amount of population and serve many applications across domains. This paper explains how to make this project come to reality and touches the main aspects of it, with work pending to do. The next steps to start getting this project come to life would be:

- Study and test the best hardware configuration of the drones and the controller for the purpose of this project.
- Implement and test SDN and the Reactive Forwarding app on real hardware, modifying it to make it more energy efficient.
- Energy consumption tracking must be made for the controller to monitor the drone's battery life and in order to gather data with the controller's applications' energy efficiency.
- Develop an application that will let the controller move the drones automatically based on the topology, the network's users, and the drone's battery life.
- Run tests and get familiarized with Starlink and its protocols.

Chapter 8

Conclusion

In this paper, it has been discussed the possibility to give connectivity and networking capabilities with the usage of software defined networking and drones with the possibility of using Starlink's network.

A detailed study of the hardware parts to use has been provided, with a selection of hardware configurations that could be most successfully combined.

The Reactive Forwarding application is a great routing protocol for mobile dynamic networks, which perfectly fits the purpose of this project.

A new process to select the path to follow is proposed, to be more energy friendly, opening the door for further modification of the ONOS's applications to make the SDN controller more energy efficient, giving a longer battery life for the drones that will act as the access points in the network. This application's changes could be used for cloud controllers as well.

It has been shown that the more drones(APs), the more saturated the controller becomes and the worse it operates, having the need to study the topology of the area where the network will be deployed, to launch the adequate number of drones that will give connectivity to the area, mainly based on its size.

Appendix A

Sustainable Development Goals of the project

This technology meets the goal number 9 of sustainable development goals established by the United Nations which is "Industry, Innovation and Infrastructure".

A functioning and resilient infrastructure is the foundation of every successful community. To meet future challenges, an upgrade in our industries and infrastructure must be done. Innovative technologies must be promoted to ensure equal and universal access to information and financial markets. This will bring prosperity, create jobs and make sure that we build stable and prosperous societies across the globe.

This project meets that objective because it presents a system in which the accessibility to the internet and all its functionality such as information access or communication will be given anywhere evading violent conflicts, and other emergency disasters, and geographical or economical restrictions.

Appendix B

Scientific paper

During this project, a scientific paper was written.
It will be published when a conference or opportunity comes along.

Networking connectivity through Drones using dynamic wireless Software Defined Networks

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***Abstract*—This paper proposes the usage of drones and SDN to bring wireless networking capabilities to remotely located areas that do not have easy internet access. It discusses a selection of hardware that can be used to provide Wi-Fi through drones. Simulations to support this project were made using Mininet-WiFi and the ONOS controller.**

I. Introduction

Drones are one of the most disruptive technologies created in the last decade. Their usage possibilities are many more than just a remote-controlled flying object, and we have just started to scrape the surface of their usages and how beneficial they could be in today's world.

Software defined networking (SDN) is a revolutionary concept that has been gaining weight these past years, being able to separate the control plane from the data plane, and to centralize the network with a controller, which is software built with applications written on a high level code, being in charge of the routing tables, protocols and algorithms in the path selection of the control plane, leaving the data plane capabilities to the Access Points of the network, decreasing the use of hardware in a network.

This paper aims to combine this two impactful technologies and all their benefits to bring connectivity and networking capabilities to areas out of reach, having a central station as the SDN controller, and using drones as mobile access points (APs), controlled by the central station, creating a dynamic mobile mesh network that will be useful for areas out of reach such as rural areas or in emergencies such as accidents, deploy zones or power loss.

On this paper simulations were made using the ONOS controller and Mininet-WiFi, and different hardware is proposed to make this project come to life. Drones will be the part of the future of telecommunications, being the perfect automated mobile Access Points, benefiting from the need of less hardware through software defined networking, creating fast dynamic networks for any type of typologies and scenarios.

An example of how the topology would look is provided on the Figure 1, in which the controller moves automatically the drones around the desired area, with backup drones staying at the central station to replace the operating drones when their battery is about to run out, letting them charge their battery at the central station while the new ones are moving around the network, making a non-stop cycle loop to provide complete availability of the network.

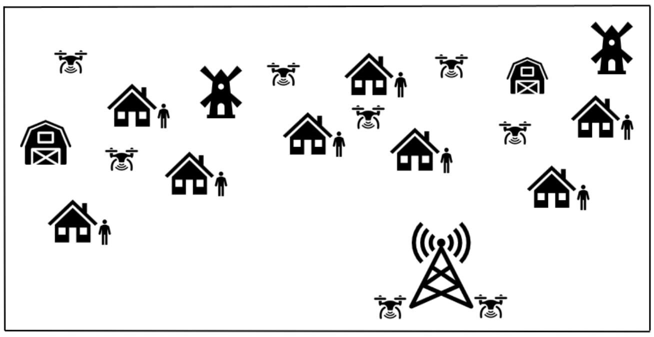

Fig. 1. Topology case scenario.

II. Related work

A. WiFi Network on Drones

There is a great paper about Wi-Fi Network on Drones experiment published in 2016 ITU Kaleidoscope: ICTs for a Sustainable world (ITU WT) [1] which goes over precise measurements and equipment used to extend the capacity or coverage of wireless systems through the deployment of aerial communications networks [1]. They use an SBC called Galileo Generation 1 which is discontinued. This SBC was compatible with Linux and Arduino, and had Bluetooth, wireless and GSM connection. The full size mini PCIe slot allowed them to use standard mPCIe modules like WI-FI, Bluetooth and SIM card adapters for cellphones. Their project consisted of deploying the aerial network with both access point-based (AP) and the ad-hoc modes. They were able to successfully create an internet access point through the drone which was at a height of 10 and 20 meters of the ground.

B. Project Loon

This was a project by Google that shut down because it was not commercially viable. This project aimed to deliver wireless internet via flying balloons in the stratosphere. The Project Loon mission was to build a network of balloons to expand internet connectivity to under-covered areas and disaster zones. Loon's giant balloons were powered by solar panels and navigated using artificial intelligence that allowed them to ride high altitude wind currents. This Project can expand the possibilities for this Wi-Fi on drone's project. A hybrid project of a drone with some type of balloon could alleviate the flight time of the drones. Decreasing the number of drones and batteries to be deployed

C. Energy Saving Algorithms with ONOS

This paper [2] presents the concept of saving energy in the network elements by avoiding bottlenecks, managing the ports used, splitting their usage so that there were not just a few ports carrying all the weight of the network. This concept is very useful for this scenario, since one of the goals to have when dealing with drones is managing their battery making it last as long as possible.

D. Drone network for Tactical Applications

Networking in tactical applications introduces additional challenges that are not applicable to conventional network and its related infrastructure. They demand an efficient way to rapidly deploy the network infrastructure with minimal costs. Usage of drones for this application is suitable for the following reasons: they cost less when compared to a traditional cellular base station (such as an eNodeB) and they can be autonomously and quickly set-up at any location (even in unsafe territories). This paper [3] studies the usage of a controllable helium-based kite to quickly deploy broadband networks for serving the US army in Afghanistan. Radio antenna mounted on the kite communicated with a geostationary satellite and achieved upstream and downstream flows in the order of 5 and 20 Mbps respectively.

E. Analyzing performance of drone small cells

The authors of this paper [4] analyze the performance of drones to support cellular networks in overloaded and critical situations. The paper studies the impact of altitude on the downlink coverage for a single drone cell acting as a base station and shows that the optimal altitude for maximum coverage can be found by calculating the minimum value of path loss exponent, $L(\theta)$. Then, they study the optimal deployment for two drone cells in terms of altitude and distance between them. Mathematical results showed that for every configuration with two drones, there exists an optimal separation distance to minimize impact of interference on coverage performance. For example, a rectangular coverage area with dimensions 2000m and 700m had the highest coverage ratio of 0.78 when the perpendicular distance between the two drones was 1100m. Results obtained from this paper provide a foundation for more work with higher number of drone cells.

F. Opportunities and challenges of drones in wireless communication

This paper [5] talks about the promises and shortcomings of using drones to provide wireless connectivity compared to terrestrial communication infrastructure. Predominantly, UAV (Unmanned Aerial Vehicle) systems are more cost-effective and can be swiftly deployed which makes them suitable for limited-duration operations. They offer significant improvement in short-range line-of-sight (LoS) communication over broadband stations that cannot provide coverage in remote locations such as dense jungles and mountain regions. Drones can be maneuvered by varying altitude and location offering new possibilities of enhanced performance. Despite these benefits, UAVs in wireless network communication come with several design challenges. Flying drones often involve obtaining stringent security permissions from various agencies. They have to be secured from mid-flight collisions such as unforeseen obstacles or bird attacks. Also, if drones have to facilitate network connectivity over vast regions, a swarm of drones have to be designed carefully with high level of coordination to ensure reliability. Another major challenge is the power and payload constraints that drones offer. Low battery capacity often limits the flight time of many drones. To tackle these shortcomings, energy efficient designs and operations, such as reducing processing power consumption, reducing payload and body weight etc. are needed for maximum usage.

For enhancing performance, the authors present two techniques, namely, UAV-enabled mobile relaying and D2D-enhanced UAV information dissemination. In the first technique, the drone divides its operation between source and destination. During the first phase, the drone flies towards the source to find δ, which corresponds to maximum tolerable delay. The drone stores the source information in its local buffer and after time greater than δ, it flies towards the destination and relays the information from its buffer. The drone then returns to the initial position at the end of cycle when time equals 2δ. In the second technique, D2D protocol is used to provide benefits such as energy saving and lowering capacity requirement for drone wireless backhaul [6]. This technique employs a two-phase process for information dissemination. In the first phase, drones broadcast the same information packets to all ground nodes as it flies over them. Due to limited wireless connectivity, the ground nodes receive only a part of the transmitted packet. In the second phase, the ground nodes exchange the remaining portion of the packets by communicating with each other. This significantly reduces the number of drone re-transmissions thereby saving energy.

III. Hardware

A. LaunchPad

A Single Board Computer are computers on a single chip, unlike traditional computers where there is a mother board and separate peripherals needed to make the PC or Mac functional. These are usually more powerful than Launchpads which are inexpensive TI prototyping tool that provides on-board emulation for programming and debugging. These launchPads are getting better throughout the years and therefore there have been listed the ones that may be able to be used to avoid using SBC due to their higher power consumption.

The first selection will be the SimpleLink Wi-Fi CC3235S dual band launchpad a single chip security and wireless microcontroller which integrates a user application dedicated ARM cortex MCU and a network processor that runs 2.4GHz and 5GHz Wi-Fi internet, and security protocols [7]. This board is very popular to implement IOT projects and are great for making mesh networks which is what will be required. An interesting fact of this board is that an antenna can be added to increase its signal strength. Wi-Fi Tx power 2.4 GHz 16dBm at 1 DSSS, 5GHz 15.1 dBm at 6 OFMD. Wi-Fi RX sensitivity 2.4 GHz -94.5 dBm at 1 DSSS, 5GHz -89 dBm at 6 OFMD.

The next board is also by TI, CC3100MODBOOST SimpleLink. This board integrates protocols for Wi-Fi and internet which greatly minimize host software requirements [8]. Transfer power, 17dBm at 1 DSSS, 17.25 dBm at 11CCK and 13.5dBm at 54 OFDM. The RX sensitivity is -94.7dBm at 1 DSSS, -87 dBm at CCK and, -73 dBm at 54 OFDM [8]. These boards are great selections for this project.

B. SBC

In case of more power required to drive our Wi-Fi network there is the option of using SBCs. Raspberry pi 4 would be an excellent choice due to the large selection of computer Wi-Fi cards that can be added, but due to its size it may limit the drone choices that could be had and may not be the most energy efficient. Instead, I a few competitors were selected which can have the require functionalities required to successfully drive our network.

Rock Pi X B4E32 can run windows 10 and it is a compact size Raspberry Pi for factor as well it includes 802.11 ac Wi-Fi and Bluetooth 4.2 to realize IoT projects with and onboard antenna and external support [9]. The size is 85mm x 54mm which is not too big of a footprint. This board also provides GbE LAN with power over the Ethernet (PoE) support.

Another board is the Rock PI 4 model C which is from the same family as the previous board. It also provides 802.11 ac Wi-Fi and Bluetooth 5.0 with on board antenna. GbE LAN with PoE support and is the same dimension 85mm x 54 mm. These two boards should be able to handle the network range but like stated before if more power is needed, the Raspberry Pi would be the next candidate because it allows for PCIE 2x1 socket which allows for broader use of stronger antennas such as EDUP PCIe Wi-Fi 6 card 2x 6dBi high-gain antennas [10].

C. Xbee

It cannot be forgotten about how the drones will be communicating to each other during the fly time. Xbees can be used to take care of this matter. Xbees are a great way to control and connect to networks and this would not interfere with the Wi-Fi network. These modules are easy to configure and very small in size. The Digi Xbee DigiMesh 2.4 has multiple antenna options [11]. Outdoor Rf Line-of-sight range up to 2 miles(3.2Km) with high gain antennas and they also provide with the cloud software to implement any project.

D. Drones

The number of drones deployed to provide Wi-Fi depends on the area required to be covered with the network as well as the distance between drones where the Wi-Fi network can still be connected form each other. Wi-Fi can have a range of around 300 feet. Another aspect that was kept in mind when selecting the drone was the flight time of the drone. Typical flight time for most high-quality drones is about 20 minutes which is not a very long time. Also, drones have a payload limit they can carry and therefore this payload can decrease the flight time as well. The Size must be big enough to carry the SBCs or LaunchPads and the battery to power it. The following drones are great candidates to choose a model from and are great for projects like these because the software and hardware can be added as required.

The ARRIS M900 4 axis Quadcopter Frame kit good for long Flight time [12]. Compatible with 6S 22.2v 12000mah to 25000mah. The flight time is about 60 minutes with 6.7Kg takeoff weight. And 30 minutes with 9.7Kg takeoff weight.

The next drone is a ZD550 pro 550mm 4 Axis carbon fiber umbrella folding quadcopter combo with motors ESC propeller [13]. Has a flying time of 20 minutes with 4s 10000mah battery.

The third drone is the ARRIS M700 umbrella foldable carbon fiber hex copter frame [14] with most of the aspects of the previous drone.

Finally, there is the Tarot Peeper Long Flight Quadcopter Super Combo TL750S1 that can fly for around 47 minutes with a 6S 10000mah Lipo battery. There are plenty of powerful batteries on the market today which makes easy to select one to accommodate the desired needs.

E. Hardware selection

The information about hardware and drones was done with the motive to find the best selection for this project. The theoretical values of Wi-Fi ranges of the boards and SBCs may not necessarily represent the real values. As for the selections of the boards, the SimpleLink Wi-Fi CC3235S dual launchPad would be selected to test. A U.FL Antenna can be added for both the 2.4GHz and 5GHz of this board. The Drone and battery for this project would be the ARRIS M900 4 axis Quadcopter frame kit because of the amount of flight time it possesses equipped with the 6S 22.2V 25000mah battery. A small battery can be added to power the boards or a PCB with a buck converter can be designed to power both the drone and the board with the same battery. The Xbees will be great for connecting the drones together and make a network they are very easy to use.

F. Continuous power supply

Keeping the drones in the air for long periods of time is crucial to making this approach to connectivity work. Long flight times require a lot of energy, and very often, drones are equipped with batteries that cannot sustain this operation.

Power cord tethers, which connect the drone to a ground-based generator can supply continuous power to the drone in flight. The tethers are made of standard 18 gauge wire and can carry a 400V DC current. Using the tether, a drone can stay in the air for very long periods of time, even through harsh weather, providing a strong, reliable signal the whole time. Hypothetically, in the event of power loss, if the tether is disconnected for some reason, the drones can be programmed to switch to a backup battery and land automatically.

IV. Evaluation of Energy Consumption

Drones will gain more popularity as flying base stations in wireless communication. However, due to their limited on-board battery, the typical flight time is restricted to less than 1.5 hours. Therefore, it is very important to design energy efficient solutions when deploying drones. To maintain uninterruptible network connectivity in the coverage area, authors of [15] proposed swapping UAVs. Fully charged back-up drones are readily swapped as soon as the battery gets drained. Another less expensive solution is to replace the drained batteries with fully charged ones, to avoid waiting for the drained battery to be recharged. This method requires additional labor costs for manual replacement of the batteries.

When considering energy costs for replacing batteries or recharging them, we have to consider the costs involved in flying the drone to and from the charging station. Authors of [16] developed a mathematical model to calculate the time a drone can hover at a hotspot based on the battery capacity. Given, T_{se} denotes the time a drone can fly at a hotspot to provide cellular service and T_{tra} is the time required by the drone to travel to and from the nearest charging station, we can define them as follows:

$$\begin{aligned} T_{\mathrm{se}} &= \frac{B_{\mathrm{max}} - 2P_{\mathrm{m}}\frac{R_{\mathrm{s}}}{V}}{P_{\mathrm{s}}}, \\ T_{\mathrm{tra}} &= \frac{2R_{\mathrm{s}}}{V}, \end{aligned} \quad (1)$$

where B_{max} is the battery size, P_m is the power consumed during travelling, V is the velocity with which the drone travels and P_s is the power consumed when the drone is hovering at the center of the hotspot. P_s here accounts for both power required for data communication and propulsion. Distance between the center of the hotspot and the nearest charging station is denoted by R_s. The value of P_s is assumed to be fixed whereas P_m is denoted as follows:

$$P_{\mathrm{m}} = P_0\left(1 + \frac{3V^2}{U_{\mathrm{tip}}^2}\right) + \frac{P_{\mathrm{i}}v_0}{V} + \frac{1}{2}d_0\rho s A V^3, \quad (2)$$

where U_{tip}^2 is the tip speed of the rotor blade, v_0 is the mean rotor induced velocity in hover, ρ is the air density, A is the rotor disc area, d_0 is fuselage drag ratio, V is the velocity of the UAV, and P_0 and P_i represent the UAV's blade profile power and induced power in hovering status, respectively.

The energy consumed by UAV for travelling between the hotspot and charging station is

$$\begin{aligned} E_t &= \frac{R_{\mathrm{s}}}{V}P_{\mathrm{m}} \\ &= \frac{R_{\mathrm{s}}}{V}\left(P_0\left(1 + \frac{3V^2}{U_{\mathrm{tip}}^2}\right) + \frac{P_{\mathrm{i}}v_0}{V} + \frac{1}{2}d_0\rho s A V^3\right). \end{aligned} \quad (3)$$

V. The Software Defined Network

A. Defining SDN

As an emerging networking architecture, Software Defined Networking (SDN) is established as a promising concept for our future. It is an efficient networking technology that supports the dynamic nature functions of our future networks with the crucial aspect of simplifying hardware through software, with many benefits such as lowering costs, and being the perfect network configuration when using drones as access points [17].

The main characteristics that differentiate SDN from any other network layer architectures are:

- Differentiation and separation of the control plane and the data plane of the switching hardware.
- Using software for the control plane functions, reducing hardware usage and requirements. That software is known as a controller, which is centralized and has a complete view of the network.
- Open interfaces between the controllers and the devices located in the data plane, which in this case will be the drones.
- Customization of the controller through applications that can be programmed by any external source or user; which will be essential when adapting the controller to the network.

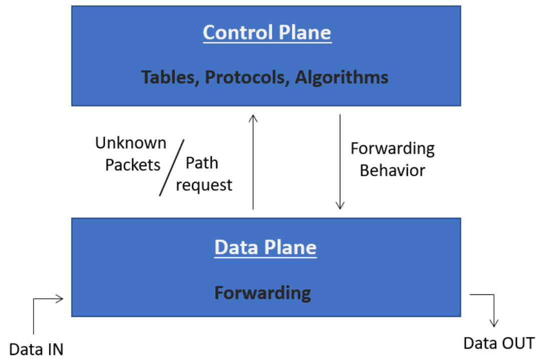

Fig. 2. Control plane and data plane schemes regarding SDN

B. The controller

When talking about the controller to use, different options can be considered:

- Ericsson controller or similar, which are cloud based SDN controllers, with the benefit of configuring the controller apps and accessing all the information in real time from anywhere with a connection, and the negative side of paying for accessing its service, and being dependent on the connectivity, loosing the control of the network topology when there is no connection.
- ONOS controller, which will be discussed in more detail later on this paper as an open source controller, with the benefit of being free, but with the downside of having to

physically and manually install it and its applications, monitoring it and the network in person and not on remote.

VI. Starlink

One of SpaceX's biggest innovations and projects is called Starlink and it consists of bringing internet access all around the world at a reduced price, giving better access and availability everywhere but especially in places where internet access was not available before.

It involves beaming internet data, but via radio signals through the vacuum of space. Ground stations on the Earth broadcast the signals to satellites in orbit, which can then relay the data back to users on Earth. To make this possible, thousands of low orbit satellites would be put in space above the Earth. The Starlink constellation could have as many as 42.000 satellites, and they would be orbiting 350 miles / 550 Km above Earth. Starlink uses SDN as well in between the satellites, in order to construct the paths to follow to send the information.

Those satellites will be able to transmit fast internet signals down to Earth, with an original download internet speed of 1Gbps, and a latency around 30ms [18]. The previously called central station will be ground hardware with a clear view of the sky will have to be installed in order to access Starlink's internet, called the Starlink kit, with an antenna (satellite dish) that will get and send the signals, a Wi-Fi router, power supply, cables and a mounting tripod. In this scenario, using a cloud SDN controller would not require to add more hardware to the equation.

That will provide a Wi-Fi network in the area where it is installed. The following step would be to use drones as Access Points to expand the network, letting all the users and devices in the expanded area get connected to it, as shown on Fig 1.

VII. Simulations

A. Mininet-WiFi

Mininet is a SDN network emulator that simulates virtual hosts, switches, links and controllers, that run Linux network software [19].

Mininet-WiFi is an extension that adds WiFi stations and Access Points (AP) based on wireless Linux drivers, which perfectly suits the wireless dynamic SDN network needs that are demanded for the simulations of this proposal, using mobile APs as drones. It supports OpenFlow, and it can get connected to the ONOS controller, which is the controller used for this project proposal.

Mininet-WiFi can run scripts programmed on Python, which gives freedom to create different topologies for different tests. Mininet-WiFi gives the tools to create your custom dynamic SDN network, adding as many hosts and APs as needed, with a defined range, and mobility with different speeds and paths that can be programmed. That can provide the perfect set up since different scenarios can be experienced such as hosts getting out of reach, or conflicts of hosts being in range with more than one AP. Tests with static hosts and APs have been made as the perfect case scenario, and also scenarios with moving drones (APs) and hosts were made in order to study how the network would behave in more extreme scenarios. The network simulated had an area of 1km x 1km, 40 hosts, and a different number of drones (APs) that will be tested, with a reliability of 120 meters, according to the data of the real hardware that would be used when building this project.

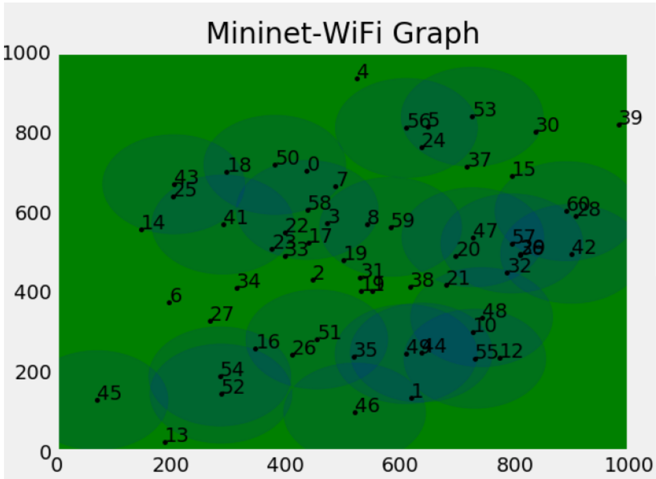

Fig. 3. Example of a dynamic topology run in Mininet-WiFi, with 40 hosts and 20 drones (APs).

B. The ONOS controller

The controller used for this project proposal's simulations is the ONOS controller; which stands for Open Network Operating System [20].

As mentioned previously, the SDN controller is built with different applications written in Java code.

One of the most important ones is the OpenFlow protocol; which has a very important role in the controller, giving access to the forwarding plane of a network switch or router, and allowing the controller to determine the route of the packets across a network. It is layered on top of the Transmission Control Protocol (TCP) and establishes the use of the Transport Layer Security (TLS).

When considering the ONOS applications to use and the forwarding application, possible options that ONOS offered and that were evaluated were SDN IP, SDN Reactive Routing, Reactive Forwarding, Path Visualization and Segment Routing. They were tested individually and combined, finding out that by just having the Reactive Forwarding app, the best packages sent/received were obtained, having a simpler controller that would have to deal with less information and types of packages in the network, having a positive impact on the drones, dealing with less packages and having a longer battery life.

Based on the previous results, the selected forwarding app for the controller is the Reactive Forwarding app; which installs forwarding entries to the network switches on-demand

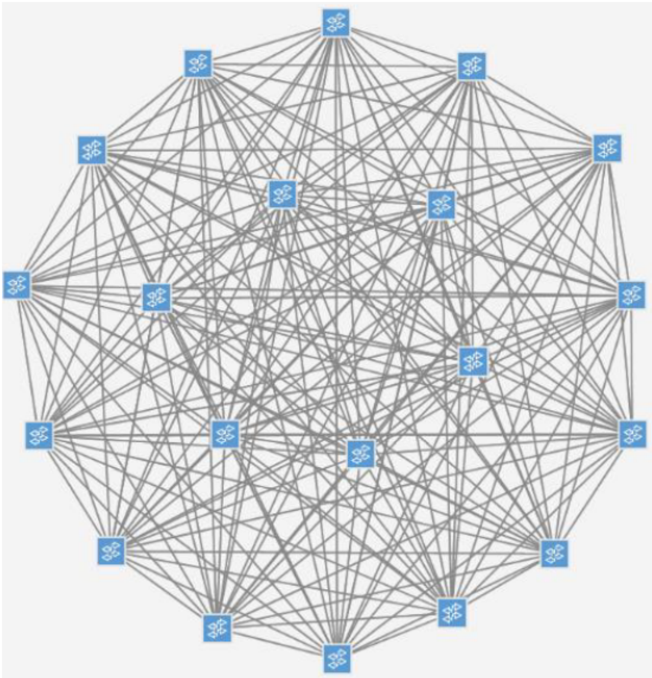

Fig. 4. Representation of an example a dynamic mobile mesh network of 20 drones (APs) from the ONOS GUI

after a sender starts transmitting packages. When a package is sent, the app handles the packet and configures the package accordingly. Because of its reactive behaviour on demand, it is ideal for dynamic networks like the one proposed in this paper.

Originally, the Reactive Forwarding app works choosing the first path available from the sender to the receiver, giving priority to the time to build the path, but for this project the application was modified to choose the paths based on the shortest paths in hops count, using the less drones possible, using the shortest path algorithm. Based on the related work section, the app was modified as well so it would not use the same path used previously, making those changes to not only focus on a few drones, giving them less use so they would have a longer battery life and a better network availability for the hosts.

```
/*
    private Path pickForwardPathIfPossible(Set<Path>
     paths, PortNumber notToPort) {
        for (Path path : paths) {
            if (!path.src().port().equals(notToPort)
    ) {
                return path;
            }
        }
        return null;
    }
*/


    private Path pickForwardPathIfPossible(Set<Path>
     paths, PortNumber notToPort) {
        Path bestPath = null;
  for (Path path : paths) { //goes through all the
     paths
            if (!path.src().port().equals(notToPort)
     ) {
     if((bestPath == null) || (path.cost()<=bestPath.
     cost()) && ((path!=oldPath) || (oldPath == null)
     )){
       bestPath=path;
    }else if((bestPath == null) || (path.cost()<
     bestPath.cost()))
       bestPath=path;
             }
  }
  return bestPath;
    }
```

Listing 1. Original Java code in the commented upper part vs modified code in the lower section

C. Experimental Analysis

Tests were performed doing a pingall in between the hosts, which would send a ping package from each host to the rest of them, displaying the connectivity between all hosts, showing how well the drone network is performing. On the best case scenario, in which the drones and the hosts were static and they could all reach each other, all the packages sent were received, having a fully operational network. However, that is not a realistic approach, since the drones and the hosts would be moving around the area of the network.

What has been studied is how the network and the controller would behave depending on the number of drones in the network, when every element of the network would constantly moving, as a more extreme situation, with an average number of ping packages sent of 1560.

# of drones	Longest time to create a path	% of packages lost
9	1 ms	-
14	3 ms	+21%
20	41 ms	+23%

Fig. 5. Comparison of network properties based on the number of drones

On Figure 6, it can be seen that the more drones in the network, the worse network quality there is, increasing the longest time to create a path by the controller, and increasing the number of packages lost from fewer drones to more drones.

The packages per second in the network can be seen in Figure 7, with the usage of Wireshark, observing a more static number of packages on the lower graph, that has to do with the controller having to deal with more APs and information that they have to send to the controller in order for it to select from the possible paths the best option, and less peaks of packages that are related to sending information from host to host. On the other hand, on the upper graph, since there are less APs to deal with, less constant information about the APS has to be dealt by the controller, and more peaks of information sent between hosts can be seen.

The controller gets saturated with too many APs in this extreme situations, showing that a study of the network, its area, topology and users has to be done so that the optimal

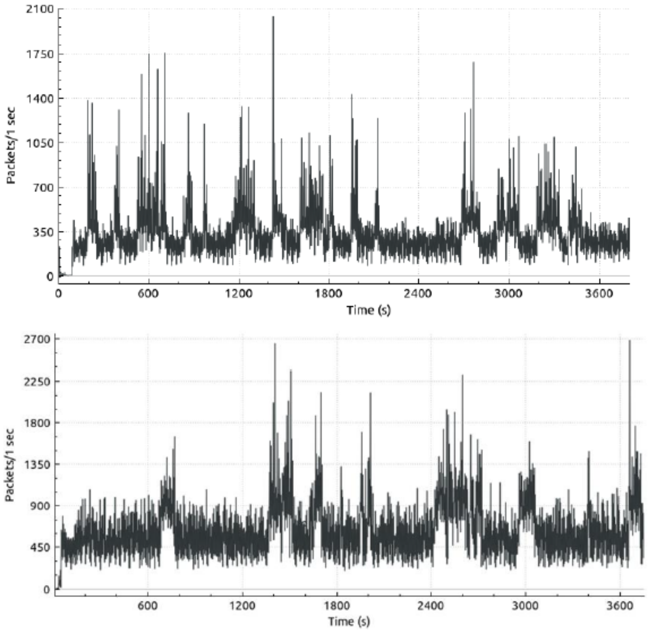

Fig. 6. Packages flow in the network. The upper graph represents the network with 9 drones and the lower graph represents the network with 14 drones.

number of drones can be deployed to have the best possible performance of the network.

This simulations show that this project could come to life and work efficiently, and that a relationship with the topology to work with and the number of drones deployed is important to have an optimal quality of service of the network, having enough drones to deal with the hole area and its hosts, and not overflow the area with drones, saturating the controller.

VIII. Future works

This paper is a proposal of a project that when fully finished, will benefit a large amount of population and serve many applications across domains. This paper explains how to make this project come to reality and touches the main aspects of it, with work pending to do. The next steps to start getting this project come to life would be:

- Study and test the best hardware configuration of the drones and the controller for the purpose of this project.
- Implement and test SDN and the Reactive Forwarding app on real hardware, modifying it to make it more energy efficient.
- Energy consumption tracking must be made for the controller to monitor the drone's battery life and in order to gather data with the controller's applications' energy efficiency.
- Develop an application that will let the controller move the drones automatically based on the topology, the network's users, and the drone's battery life.
- Run tests and get familiarized with Starlink and its protocols.

IX. Conclusion

In this paper, it has been discussed the possibility to give connectivity and networking capabilities with the usage of software defined networking and drones with the possibility of using Starlink's network.

A detailed study of the hardware parts to use has been provided, with a selection of hardware configurations that could be most successfully combined.

The Reactive Forwarding application is a great routing protocol for mobile dynamic networks, which perfectly fits the purpose of this project.

A new process to select the path to follow is proposed, to be more energy friendly, opening the door for further modification of the ONOS's applications to make the SDN controller more energy efficient, giving a longer battery life for the drones that will act as the access points in the network. This application's changes could be used for cloud controllers as well.

It has been shown that the more drones(APs), the more saturated the controller becomes and the worse it operates, having the need to study the topology of the area where the network will be deployed, to launch the adequate number of drones that will give connectivity to the area, mainly based on its size.

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Appendix C

Project Management perspective

After this project is fully proposed on a theoretical level, a high level proposal as a project manager is designed showing how to accomplish it in one semester, at a University of Florida laboratory, covering: Problem Statement, Critical Success Factors, Project Scope and Deliverables, Work Breakdown Structure, schedule, and network diagram, Project resources and/or organization, Project Budget, Quality Management Plan, Health and Safety Plan, Risk Management Plan, and the Closeout Plan.

Project Management perspective

1. Problem Statement

The problem that will be worked on is the lack of wireless internet connection and communication in rural areas and in emergency situations such as power losses in a city, or in temporary deployments.

In order to solve this issue, drones will be used, that will expand a WiFi network using software defined networking. Those drones will be connected to a mobile base station, that will coordinate the drones and stablish the connection of the WiFi network to the internet through satellite internet, using Starlink's services.

This project proposes the usage of drones and Software Defined Networks to expand Starlink's network capabilities to bring wireless networking capabilities to areas that are out of reach and that do not have internet access.

An example of how the topology would look like will be provided below on Fig 1.

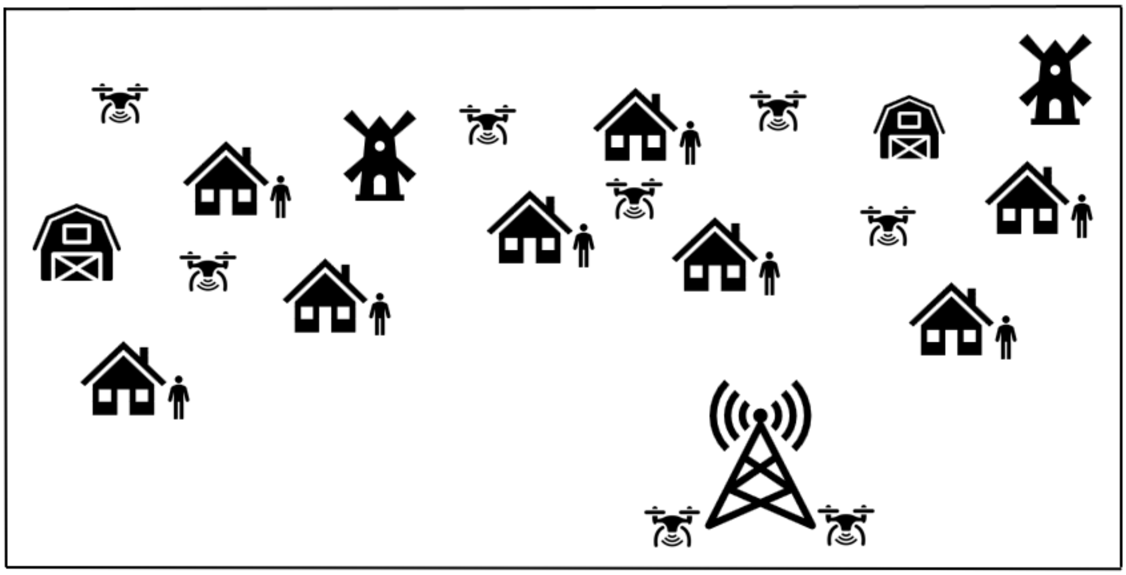

Fig 1. Topology example

2. Critical Success Factors

Project Requirements for the project to be successful

- Quality of Service of the network
- Reliability of the network
- Cybersecurity of the network
- Back up drones so that there is constant availability
- Contract with Starlink
- Operational protocols for the network
- Emergency plan due to weather restrictions

- Optimal configuration of the drones' hardware and software
- Optimal configuration of the base station's hardware and software
- Simulations to test possible network configurations in each different type of area

3. Project Scope and Deliverables

First, a research and selection of the most optimal hardware parts to use for the drones would be needed. After that, the required software must be installed on the drones, developing and learning about the protocols that must be used in the network. Drones that are able to communicate with each other and that would fly and stay active properly would be needed to have after those steps.

Starlink's network system would be used, so there would have to be a learning process about their protocols and also contact them to use their resources to create the WiFi network on the desired area.

The hardware components of the base station would be Starlink's antenna/kit, and it would be needed at this point to perform tests with the step of creating the software and protocols that the drones will need to expand and use Starlink's satellite internet network.

A study of the number of drones needed to be on the air and as a backup on each specific area must be conducted.

After all those steps, simulations must be made in order to change any of the obtained previous information, followed by tests to check for the functionality of the network, implementing the new found data until the optimal configuration is obtained.

When the tests offer positive results, start contacting clients and produce the mobile network for them, ready to deploy in combination with Starlink.

4. Work Breakdown Structure, schedule, and network diagram

This is a project that I have been working on this semester for research, so I will base sections 4, 5 and 6 on this real life situation, with extra data from the internet such as salaries.

Task Mode	Task Name	Duration	Start	Finish	Predecessors
	Research and select most optimal hardware components for the drones	4 days	Wed 1/5/22	Sun 1/9/22	
	Install the software required to the drones to run the network	11 days	Mon 1/10/22	Sat 1/22/22	1
	Research about Starlink's network protocols	6 days	Mon 1/24/22	Mon 1/31/22	2
	Contact Starlink to use their services	10 days	Tue 2/1/22	Mon 2/14/22	3
	Select the hardware to use for the base station	5 days	Tue 2/15/22	Mon 2/21/22	4
	Install and develop software for the base station to control the drones and connect them to the network	16 days	Tue 2/22/22	Tue 3/15/22	5
	Study of number of drones needed on the air to support each type of area and back up drones needed	8 days	Wed 3/16/22	Fri 3/25/22	6
	Run simulations and gather data	10 days	Mon 3/28/22	Fri 4/8/22	7
	Run tests to check functionallity	15 days	Mon 4/11/22	Fri 4/29/22	8
	Contact clients to develop and deploy network	1 day?	Mon 5/2/22	Mon 5/2/22	9

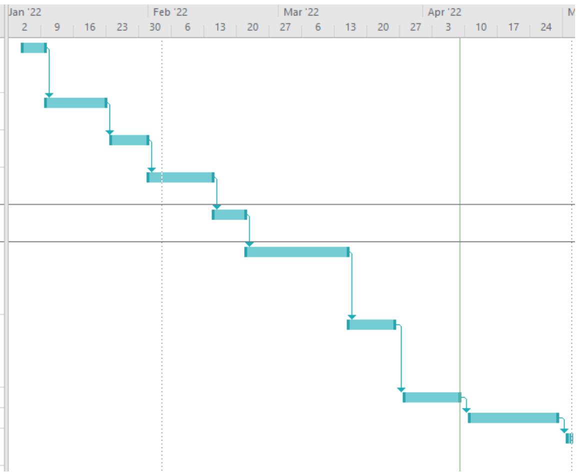

Fig 2. Gantt Chart

Fig 3. Network diagram

As it can be seen on Fig 2 and Fig 3, there is just one critical path, since every task depends on the previous one, making this a more sensitive project in case any of the tasks gets delayed or fails.

The working times are based on a regular calendar, from 8AM to 12PM, and from 1PM to 5PM, from Monday to Friday.

5. Project resources and/or organization

Resource Name	Type	Material	Initials	Group	Max.	Std. Rate
Project Manager	Work		PM		100%	$50.00/hr
Research assistant	Work		RA		400%	$14.00/hr

Fig 4. Resource Sheet

Fig 5. Organization chart

As it can be seen on Fig 4 and Fig 5, there is a project manager, who is responsible on supervising the project and coordinating the 4 research assistants, who are in charge of researching and developing all the software and hardware tasks.

6. Project Budget

The salaries used can be seen on Fig 4, with a salary of $50/hr for the project manager, and $14/hr for the research assistants. The cost estimate can be seen on Fig 6, with a total of $72,928.00

	Start	Finish
Current	Wed 1/5/22	Mon 5/2/22
Baseline	NA	NA
Actual	NA	NA
Variance	0d	0d

	Duration	Work	Cost
Current	84d	3,440h	$72,928.00

Fig 6. Cost estimates

7. Quality Management Plan

The quality management team would ensure high quality products and services, eliminating defects and making continuous changes and improvements in the system. It would plan, measure, analyze and report on quality. It would also support other departments with the improvement of products and services.

In this case, a good quality of the network must be met, meeting reliability, latency, capacity, and security standards not just to provide a great service but also to be able to manage it. High capacity load balancing, scalability, a good network management system, role based access control, the ability to measure performance, network access control, an optimal firewall, and redundancy in between the drones is key for a great assured quality, and to provide an efficient quality management.
There must be extra drones in case any have a failure or their batteries drain, in order to change them on demand to guarantee the proper availability of the services.

Software and hardware updates and upgrades must be studied and performed at all times when needed.

8. Health and Safety Plan

The main potential hazard is drones running out of battery and making damage.

To mitigate this, there will be an automatic safety system that will save a small percentage of battery of the drone to slowly descend to the ground while emitting a loud beeping sound so that any possible close people could be aware and can move accordingly so that the drone does not crash with anybody. If a battery failure happens and it gets suddenly shut down, drones will deploy a small emergency parachute to descend slowly, having as well an air bag system in which if it hits anything with over a studied amount of force, it will not make any damage.

9. Risk Management Plan

The main risks are: Going over budget, Unexpected weather conditions, Poor management, Inadequate data, Taking longer than expected, Simulations far from reality, Network not meeting the standards, and Drones causing damage, which are addressed on Fig 7

Risk	Risk Statement: Condition	Risk Statement: Consequence	Probability (%)	Impact ($)	Exposure ($)	Mitigation	Contingency	Triggers	Assignee
Briefly describe the identified risk	Capture the "likely cause" of the risk. Be detailed enough so that you can start forming mitigation plans.	Capture the result of the risk, should it happen.	Estimate of the probability the risk will occur. (use this probability in your Monte Carlo	Estimate of the amount of impact or severity of the risk. (use this as worst case in Monte Carlo)	Probability x impact in $. Sort by this column to prioritize biggest $ risks. (use this as most likely case in Monte	Document plans to lower the probability or to lower the impact ahead of time.	Identify what would have to be done if the risk were to become reality.	Identify what would prompt you to execute the contingency plan.	Identify who is responsible for tracking this risk and its changes in probability and impact. The assignee is not necessarily the person responsible for solving the problem, as risks often require escalation outside the team.
Going over budget	Encountering problems or conditions that would require to invest more money than the	Poor reputation, disbelief of the project, lose investors, legal problems, and leave the project	10%	2000	$ 200	Make a risk identification and plan the budget according to the possible risks that could be found to have back up money to	Talk to the investors and ask for more money, giving them a compensation for their trust and loyalty.	Unexpected problems when developing the drones or the software for the network	Project Manager
Unexpected weather conditions	Unexpected weather that could damage the drones	Extra investment in new drones or parts.	30%	1000	$ 300	Make a in real time analysis of the weather, programming an automatic turn back to the base of the drones when the weather conditions are dangerous.	Run the emergency software on the drones to return to the base, and locate the ones that could not come back to get inspected and repaired if needed.	Sudden and drastic weather change	Project Manager and Software/Hardware developers
Poor management	Change the plan midway on the development, not make a risk/failure analysis, developping a poor plan.	Failure of the project, going over budget, taking longer than expected, and not having possitive outcomes.	5%	2000	$ 100	Risk/failure analysis must be made, making a plan with all the possible problems and solutions/outcomes.	Meet with the project manager and have a full comunication to make sure the right path is being followed, and that there are not more changes.	Unexpected problems when developing the drones or the software for the network	Project Manager
Innadecuate data	Impropper gathering of test data	Missbelief in properties of the project that would lead to poor and unrealistic development of the	5%	1000	$ 50	Contrast new data gathered with data used in the past or in other projects	Analyze the data available, and delete the ones that are not well obtained	Findings in wrong data gathering	Project Manager and Quality Check Team
Taking longer than expected	Encountering problems or conditions that would require to invest more time in fixing them	Poor reputation, disbelief of the project, lose investors, and legal problems.	15%	500	$ 75	Make a risk identification and plan the time needed according to the possible risks that could be found and the time required	Add more resources to the future tasks to catch up on time	Unexpected problems when developing the drones or the software for the network	Project Manager
Simulations far from reality	Simulations that are not true to reality, with wrong imput data or unrealistic simulations	Wrong development of the project, costing time and money.	15%	100	$ 15	Make sure to fully send and check the information used, and analyze the results to verify that the logic used for the simulations is the correct one.	Redo the simulations	Data found not to be propperly exported to the simulation, or results far from what is expected in reality.	Project Manager and Software/Hardware developers
Network not meeting the standards	Security breaches, unreliability, poor quality of service.	Poor reputation, losing clients and investors	5%	2.000	$ 100				
Drones causing damage	Failure i the programming or batteries of the drones, causing them to fall down	Damages to the drones, propperty, machines, or people.	5%	4.000	$ 200	There will be an automatic safety system that will save a small percentage of battery of the drone to slowly descend to the ground while emitting a loud beeping sound so that any possible close people could be aware and can move accordingly so that the drone does not crash with anybody. If a battery failure happens and it gets suddenly shut down, drones will deploy a small emergency parachute to descend slowly, having as well an air bag system in which if it hits anything with over a studied amount of force, it will not make	Get new hardware/drones, pay for the health or property damages	Battery shut down, or low battery	Project Manager and Software/Hardware developers

Fig 7. Risk Register

10. Closeout

I have realized after doing this project, how important it is to set the bases for any new project with the scope of work, critical success factors, and to make a complete analysis of the project such as risks, and how to mitigate them or having a contingency plan, with the addition of using MS project for the study of resources, costs, tasks, timelines, and more with its powerful tools.

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