A Simulator for Creating Drones Networks and Providing Users Connectivity

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***Abstract*—Unmanned aerial vehicles are devices able to perform many different tasks that can help human activity in many processes. One of the most important use regards the possibility of giving wireless connectivity to user in a specific area. These new typologies of networks are called Flying Ad-hoc Network. Their use benefit all those situations of emergency where the traditional communications may have many issues, due to the specific event. Different types of natural disasters (such as climatological, meteorological, hydrological, geophysical) can result in many deaths and many economic damages. In these situations, drones can provide an additional or complementary access network, supporting web services and multimedia traffic, helping people involved in the rescue. Hence, it is clear that the possibility of using a simulator can result in a huge help to the research community. So, in this work, a Flying Ad-hoc Network simulator is proposed, able to simulate different scenarios with different coverage areas. In particular, emphasis is given to new coverage and human mobility models, in order to support more realistic situations. Some simulations have been led out to show how the simulator works.**

***Index Terms*—FANET, UAVs, Drones, Connectivity, Coverage Model, Human Mobility Model**

I. Introduction

Unmanned Aerial Vehicles (UAVs) is widely used for providing wireless connectivity in a specific coverage area. Thanks to this ability these devices can be used in many emergency situations where temporary communication networks can give an important help in the situations of rescue. The network composed of a team of UAVs/drones is known as Flying Ad-hoc NETwork (FANET), a particular kind of Mobile Ad-hoc NETwork (MANET), in which the mobile nodes are able to construct self-organizing networks with flying aircrafts in the sky [1]. This new kind of network can be employed in overall situations where it is important to guarantee an efficient and prompt communication, that is in many emergency situations or in disaster events where the communications are a fundamental aspect in order to save human lives. The coverage aspects provided by UAVs/drones are an important research topic, as it is possible to view in the recent literature. These new technologies aim to maintaining a certain quality of transmission basing also on devices movement prediction [2]–[4]. Moreover, the cooperation between these devices represents an important aspect and, it is important to study the coordination techniques able to create group of drones that collaborate together, paying attention to energy [5] and channel state [6], [7] conditions.

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The main task of this paper is to provide a new simulation environment in which it is possible to create ad hoc coverage situations in order to simulate the UAVs/drones behavior in the providing multimedia traffic for users that request connectivity in their footprint. The proposed simulator is realized in Java and it permits the simulation of different scenarios and situations in which users need to communicate each other. The simulator can import real maps (got by Google) on which the user can insert a set of Points of Interests (PoIs) that represent the points in which users move in order to reach the prefixed destinations. The simulator presents a Graphical User Interface (GUI) for allowing to set a series of simulation parameters, such as users mobility, drone height and coverage radius, different typologies of users and the percentage of these typologies in the considered map, types of multimedia traffic and their percentage in the simulation and much more. Moreover, the paper proposes two new models, a human mobility model, that tries to provide a way the users utilize for moving in the covered area, and a footprint (coverage) model, able to model the drone channel for calculating the correct height of the drone on the base of the coverage radius. Moreover, in order to evaluate the available bandwidth for the drones in the path followed by the users in their movements a standard link state protocol has been considered in which the topological changes are due to change in the parameters status (bandwidth along the path) and the protocol updates are operated on periodical base. The results of our simulation campaigns are shown in order to validate the goodness of the proposed software simulator. The rest of this paper is organized as follows: section II presents the related work on the considered research topic. In section III, a description of the FANET simulator is given. In section IV, we describe the simulation environment created in java and the simulator implementation details. The numerical results are presented in Section V. Finally, section VI concludes the paper.

II. Related Work

In the last years a lot of research has been focused on the UAVs technology. Many researchers have analyzed and studied several aspects of these new devices in order to show their potentiality and capacity in many real contexts. Some works are focused on the creation of ad-hoc simulators able to permit the researchers to analyse many UAV characteristics. The applicative domains regard a lot of scenario such as: precision agriculture, coverage, emergency and so on. In this secion, we analyse the literature in order to show how the research is pointing on UAV simulators and on the capacity of providing connectivity in a specific area.

A. UAVs/Drones software simulator

In this paragraph some of the literature works about simulators proposed for UAVs/drones devices under different points of view and applicative domains will be presented .

The papers [8], [9] propose a simulator suitable for the agriculture domain in order to design novel coordination and control techniques of a UAVs team. Moreover it is possible to define the main variables and parameters of this domain of interest. The works presented many coordinate techniques, both for monitoring the area and for coordinating the actions of the drones in the presence of parasites, in order to analyze how the performance can significantly change if more constraints, such as energy, communication range, resource capacities, are accounted.

In [10] the authors present the development of a virtual reality simulator for the management of a UAV, focused on improving the quality of life of grown-up people. The present research has collected characteristics of gestures and physical movements from users made by other related research in order to study the same interaction within a virtual world.

In [11] the authors adopt the popular approach of leveraging the X-Plane flight simulator to simulate the environment and aircraft dynamics. This approach has found recent success in visualizing and optimizing algorithms for basic UAV flight control as well as formation flight.

In [12] the authors describe a novel simulation architecture to implement distributed networked control systems. Their proposal consists in the integration of already-present and validated solutions into a compact package that features scalability and negligible architectural delays.

The purpose of [13] is to build a real-time flight simulator for quadrotor systems and verify if the simulator runs in real-time. The simulator was constructed by writing the mathematical models of quadrotor dynamic in MATLAB/Simulink. The simulator can be very useful for researchers to understand the character of the quadrotor system being developed and for pilots to complete a mission using the quadrotor system.

B. UAVs/Drones coverage aspects

In this paragraph some works about coverage issues are discussed. This research field is heavily analyzed because the FANET represents a technology able to improve and guarantee a prompt help in many real emergency situations. Then, many aspects of the coverage and connectivity issues are object of study.

In [14] the authors provided a statistical generic Air-to-Ground RF propagation model for Low Altitude Platforms, that can substantially facilitate the planning efforts of airborne wireless services, since the RF planning can be performed based on merely simple urban parameters, rather than depending on site specific 3D-models that are unlikely to be easily available and updated.

In [15], an effective coverage decision algorithm is proposed, which aims at providing seamless handover and thus establishing a fully connected aerial network. They further calculate the seamless handover success probability and the false handover initiation probability to evaluate the proposed coverage decision algorithm.

Paper [16] studies the coverage aspects of a low altitude platform (LAP) system that can form a temporary communication network. The system consists of multiple autonomous drones equipped with dual-band Wi-Fi access points (APs) with ad hoc capabilities to form a mesh network. The suitability of the LAP system is evaluated from the coverage point of view with calculations and simulations.

In [17], the authors intend to study the optimal deployment density of Drone Small Cells (DSCs) to achieve maximum coverage considering the inter-cell interference. Due to the high altitude, the air-to-ground channel of DSCs consist of probabilistic Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) links, causing computational difficulties in performance analysis. To accurately analyze coverage performance, they calculate the cumulative intercell interference considering both LoS and NLoS links.

III. UAVs/Drones Simulation System

In this section the simulation system will be presented. Our simulator has to be able to create a UAVs/drones network that covers a city and can communicate each other exchanging protocol messages. So, the created network is able to guarantee an appropriate connectivity to the users that required the connection and that are in the coverage area managed by UAVs/drones devices. The software simulator allows the setting of a series of parameters and to analyse network behavior in terms of bandwidth occupation, delays and lost packets. The area covered by UAVs/drones platforms can be represented by a real map, extracted from Google Maps site in order to make the proposed environment extremely general and parametric. This permits of considering each area in which we want to analyze human movements, on the basis of the chosen characteristics, while users exploit their multimedia applications, such as video streaming and VoIP applications. The covered area contains a set of information that regard: 1) number of humans present in the map; 2) number of clients classified by typology; 3) number of used drones for covering the considered area; 4) size of the field (for simplicity we assume a quadratic area); 5) list of PoIs that represent users destination points.

The main actors in the simulation environment are represented by two categories: 1) *Drones*: they guarantee the efficiency of each protocol that is implemented, such as the Link State, for the realization of the network. They are the relay points on the air and allow the packets exchange between source and destination; 2) *Clients*: they represent users that are moving into the map, exploiting the FANET connectivity

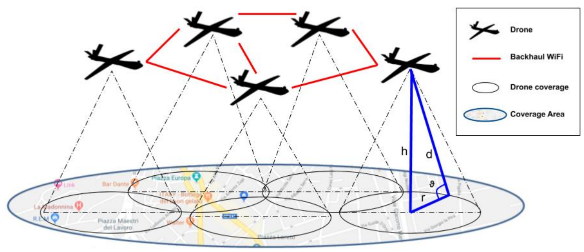

Fig. 1. Reference scenario with drone coverage footprint.

for communicating each other, using multimedia applications like video and audio streaming. They will follow a specific mobility model (illustrated in the following). Each client is also able to send many information, such as his position, to the others who request it.

For the realization of the FANET network we have relied on a classical graph structure, in which the nodes represent the Drones and the Clients and the links represent the connections between them. The obtained graph is sparse, since the number of edge departing from a node is independent from the number of nodes in the graph. In fact, the network will be created by exchanging messages between the nodes, if these are at a distance that allows this communication. So the number of links varies, according to the number of nodes in the network and to their distance. A key feature of our simulations is to keep track of changes in link bandwidth, which is why, in addition to information regarding the distance between nodes, an edge stores the bandwidth parameter. Furthermore, an edge is always identified by the pair of interconnected nodes. To manage the proximity information between nodes, a list is created for each vertex where neighboring vertices will be stored.

A. Link State Protocol for FANET creation

In this section the messages exchange between UAVs/drones devices for the creation of FANETs is described. We considered the use of Link State protocol as routing protocol for the exploration of the path between a source and a destination. The main feature of the simulator is its capability of managing itself autonomously, throughout the exchange of protocol messages in the cases of topological changes or link degradations/creations (these changes regard the metric used in the protocol). In order to simulate a real propagation condition, we have considered that the time that a message takes to reach its destination is given by the sum of propagation, transmission and processing times.

In the following, the messages sent for the creation of the FANET:

- **HELLO**: allows establishing the connection between drones and between drone and client;
- **ACK**: drone response to the HELLO message;
- **BYE**: allows the disconnection from the drone, both for drones and for clients;
- **LSA (Link State Advertisement)**: contains the Link State Table of the reference drone and will be forwarded in flooding to all the nodes of the network.
- **LSU (Link State Update)**: is a LU collector. It allows network traffic reduction.
- **LU (Link Update)**: it is not a proper packet of the standard Link State operation. It is a message that the drone sends itself whenever there is a band update of one of its links. To reduce traffic, they are grouped in a single LSU message that will be read at pre-set times (usually 30 seconds). During the reading, the drone keeps track of the status changes of its links and at the end it will update its LSA Database and generate an LSA packet that will contain its own table of neighbor nodes with updated bandwidth capabilities.

Each protocol packet contains the following general information: 1) the node ID that represents the identification of the node; 2) a sequence number that will be increased for each generation; 3) a numeric value to represent the Time To Live (TTL) of the packet. Each drone created in the simulator will have two tables that will continue to update during the simulation:

- **LSA Table**: it keeps track of neighboring nodes. This table will be the one that is sent in case of topological changes. In fact, if the drone realizes that some neighboring node is no longer connected, or notices a change in the status of the links, then it will put the related changes in this table and forward it to the neighboring nodes via LSA message.
- **LSA DB**: it keeps track of all the information on the network and will be created and modified each time an LSA is received.

When the simulator starts, each drone must send a *Hello* message to the nearby drones. The neighboring drones are all those drones that are within a certain range of coverage (we considered $300 meters$). The neighboring drones will answer and, upon receiving the *Ack*, the drone that made the *Hello* request will create a new connection within its own *LSA DB* and its own *LSA Table* composed like in Fig. 2.

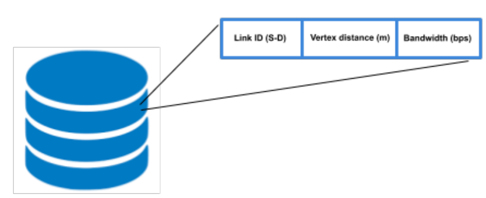

Fig. 2. New record of LSA DB or LSA Table.

Once all the *Ack* have been received, the drones generate a *LSA* packet which will be forwarded to all the neighboring nodes, which process the data in the table contained in the packet and update their *LSA Database*. They will then forward the received *LSA* packet to all the neighbors, except to the node from which they received it. Obviously, in this way, it will be possible to obtain equal *LSAs* from several drones and, in fact, a check on the sequence number of the received *LSA* packet is always performed. Each drone stores a list consisting of pairs of values that will indicate:

- the ID of the nodes from which an *LSA* was received;
- the highest sequence number relative to the *LSAs* received from that specific node.

If an *LSA* is received with a sequence number lower than that stored in the list then it will be discarded and it will not managed. The *LSA* packets will then be sent in flooding in the network whenever there is a topological change (e.g. a client connects or disconnects from the network).

B. Human Mobility Model in Urban Scenario

In order to make our approach more realistic, we have considered a human mobility model that proposes a classification of people behavior on the basis of different classes of interest. Our approach is based on a study operated by University of Milan [19] that has analyzed a dataset based on smartphone call information in Milan for 67 days detecting over 69 million phone calls and over 20 million text messages. Moreover, their study has also analyzed the WiFi and GPS datasets with founding the movement of 178 people within 4 years (between 2007 and 2011). This huge amount of data has allowed of obtaining a model of mobility of people based on the classification in 3 categories of Points of Interest (PoI) that are visited daily:

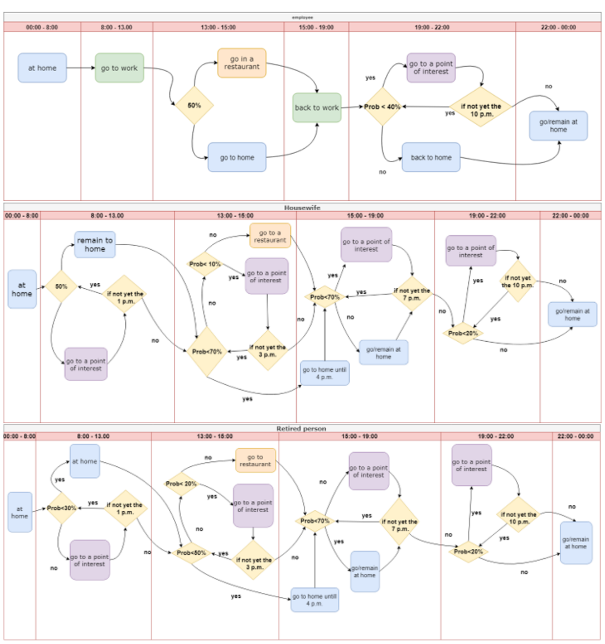

Fig. 3. Human Mobility Model for three different types of users

- **Mostly Visited PoI (MVP)**: the places most visited by users (they may be their workplaces, or their homes);
- **Occasionally Visited PoI (OVP)**: the places of interest of a user, but occasionally visited. Often they correspond to favorite places or meeting points visited during the week;
- **Exceptionally Visited PoI (EVP)**: points of interest rarely visited.

We have particularized this study introducing in the mobility model a classification of the possible behavior of the people involved in a specific map. In our study, we have considered an urban scenario in which the possible moving actors can be of three different typologies:

- **Worker**: who represents the classic type of person who spends most of the day at work. The students can fit also into this category;
- **Housewife**: who represents the type of person who spends most of the time, especially in the morning, at home;
- **Pensioner**: who represents the type of person who is free to move.

Each type of user will spend the time of the day in a different way and will visit most likely the points of major interest, also based on time slots, so we tried to represent this mobility in the simulator by considering the following models, see figure 3.

C. Footprint Coverage Model

In this paper we have considered a channel model for urban space that consists of two main components, that is a Line of Sight (LoS) and a Non Line of Sight (NLos) one [14], considered separately and then studied with different occurrence probabilities. The probability of receiving LoS and strong NLoS components are significantly higher than fading [18]. Therefore, the impact of small scale fading can be neglected. A common approach to model air to ground propagation channel is to consider LoS and NLoS components along with their occurrence probabilities separately. Note that for NLoS connections due to the shadowing effect and reflection of signals from obstacles, Path Loss (PL) is higher than LoS. Hence, in addition to the free space propagation loss, different huge path loss values are assigned to LoS and NLoS links. As it is possible to view in figure 1 a coverage area of a Drone is characterized by some parameters, they are h, the height of the drone, r, the coverage radius, d, the distance between an user on the edge of the coverage area and the drones in the sky, whose formula is: $d = \sqrt{r^2 + h^2}$, and θ, the angle (in radiant) between r and d whose formula is: $\theta = tan^{-1}(h/r)$.

On the basis of this consideration, it is possible to provide a formula for the Path Loss, PL, for LoS/NLoS conditions as in [14]:

$$PL_{LoS/NLoS}(dB) = 20log(4\pi f_c d/c) + \xi_{LoS/NLoS} \quad (1)$$

where $PL_{LoS/NLoS}$ is the average (PL) for LoS/NLoS links, $\xi_{LoS/NLoS}$ is the average additional loss to the free space propagation loss which depends on the environment, c represents the speed of light and f_c the carrier frequency. The probability of having LoS connections at an elevation angle of θ is given by [17]

$$P_r(LoS) = \frac{1}{1 + \alpha \cdot exp(\beta[(180/\pi)\theta - \alpha)]} \quad (2)$$

where α and β are constant values which depend on the environment (rural, urban, dense urban, etc.). The NLoS probability is $P_r(NLoS) = 1 - P_r(LoS)$. Equation 2 indicates that the probability of having LoS connection between the drone in the sky as Access Point (AP) and the users in the coverage area is an increasing function of θ. This means that by increasing the elevation angle θ, the shadowing effect decreases and clear LoS path exists with high probability. Finally, the average PL as a function of the altitude h and coverage radius r becomes:

$$\bar{PL}(r, h) = P_r(LoS) \cdot PL_{LoS} + P_r(NLoS) \cdot PL_{NLoS}. \quad (3)$$

On the basis of the previous drone channel model we want to provide a formula for computing the optimal altitude h for the maximum ground coverage area of radius r. Let us consider, for a drone, the transmission power P_{TX} and calculate the received power as $P_{RX}(dB) = P_{TX} - PL(r, h)$

Once the received power P_{RX} is calculated, an user in the coverage area of the drone at an height of h is able to receive the signal if its Signal to Noise Ratio (SNR) is greater than a set threshold (γ_{th}). This means that:

$$\gamma(r, h) = \frac{P_{rec}}{N} > \gamma_{th} \quad (4)$$

where N is the noise power. From the previous formula, it is possible to assert that to find the maximum achievable coverage radius we should have: $\gamma(r, h) = \gamma_{th}$. For a fixed transmission power, the optimal drone height which results in maximum coverage is computed by solving the following equation as it is possible to view in [18]:

$$\frac{180(\xi_{NLoS} - \xi_{LoS})\beta Z}{\pi(Z + 1)^2} - \frac{20\mu}{log(10)} = 0 \quad (5)$$

where $Z = \alpha \cdot exp([(180/\pi)tan^{-1}(\mu) - \alpha])$ and $\mu = h/r$. By solving equation 5, h_{opt} and r_{max} are found. We have considered the following parameters' values: f_c=2 GHz; ξ_{LoS}=1 dB; ξ_{NLoS}=20 dB; α=9.6; β=0.28 and γ_{th}=10 dB.

IV. UAVs/Drones Simulation Environment

The considered map in this work is a map of the centre of the city of *Cosenza*, a town in the southern of Italy. In particular the map was centered in the following coordinates 39.306384, 16.248832 extrapolating it by Google Maps platform. Some PoIs have been chosen, such as shops, restaurants, hotels, churches, etc. and then people's homes: a grid of 144 houses was chosen to cover most of the map. Subsequently, pedestrian movement has been realized. Each person will start their day at 00:00 and will stay at home until 8:00 am. Later, based on the proposed model, people will move during the day in the map on the basis of their own behavior as it is possible to view in figure 3. In the simulator it is possible to set, in addition to the number of people, the percentage of the three typologies of users (workers, housewives and pensioners). Simulated people movements occur in a deterministic way on the basis of the specific probabilities through the choice of a random number. In particular, in this way, the next destination will be determined for simulating human mobility. Once the next destination is determined, each person will try to reach it by following a path. The search algorithm of the proposed best route consists in the searching, each time, for a next PoI of crossing, that can be reached within a radius of 90 meters from the actual point, exploiting a grid arrangement of the PoI in the considered map. To better understand the motivation, it possible to observe the figure 4 as an example: a person must start from point S and must reach point D. Within his range of action, points 1, 2 and 3 are present and among these is point 2 which satisfies the conditions of the algorithm, in fact, it is the point reachable from S closer to the destination.

Fig. 4. Example of search for the next PoI to reach by source S towards the destination D. It is possible to view that the point 2 is the point closer to the destination D.

A person performs his movements towards the chosen destination, moving at a speed of 3 km/h. There is a procedure that is the heart of the whole movement. If, after a movement, the destination has not been reached, the procedure recursively recalculates the next PoI, generating again the events for the movement. When the destination is reached, two other events are started. These events make it possible to establish moments of pause in people's mobility and these moments vary according to different situations. Usually, a person who is not working or is not at home can stay in a PoI with a time varying between 10 and 60 minutes each time. All activities end at 22:00, the limit beyond which the day of the people is considered concluded, persons will return at home and, simultaneously, this event determines the end of the simulation.

The implementation of a FANET (drones network) in a software simulator has been realized in this work. The software is able to simulate a coverage connectivity offered by UAVs/drones devices in a specific area in which users can communicate using multimedia applications. In particular, two types of traffic have been implemented in the simulator, video streaming and VoIP calls. The considered scenario is centered in *Cosenza*, in the southern of Italy, that is the town in which

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Drones number	9
Drone bandwidth	10 Mbps
Drone coverage range radius	175 meters
Drone inter-distance	252 meters
Drone optimal height	120 meters
Drone buffer size	50 packets
Drone communication range	300 meters
People movement speed	3 km/h
People number	50-100
PoI inter-distance	90 meters
PoI number	166 (144 houses 22 shops, restaurant, entertainment)
Users' distribution	70% workers 20% housewives 10% pensioners

users move during the day. This map has been extracted by Google Maps platform considering real coordinates. In particular, we have considered the surrounding area of "*Corso Mazzini*" (one of the most important street of the city) where the users moving in this area are able to make audio or video calls. Three different simulation campaigns were carried out, in which the chances of having more or less video or audio streams in the network were changed. In the following, the probabilities considered in our simulations are shown (videos and calls distribution), classified in three different scenarios:

- 30% of VoIP calls and 70% of Video calls;
- 50% of VoIP calls and 50% of Video calls;
- 70% of VoIP calls and 30% of Video calls.

Simulations were carried out considering the number of users in the area of interest in increasing (50, 75 and 100 users). In addition to the variable parameters, various fixed parameters have been set for the simulative campaigns. In the simulator we have considered drones without problems of autonomy, each user is able to make a call each time it is in a PoI. In the proposed mobility model, the 70% of workers spend most of their time at work. Table I shows the simulation parameters.

For all the simulations, a network topology consisting of 9 drones, with a distance of 252 meters each other, and disposed in rows of 3 has been considered (in this way the most of the area of interest is covered). The resultant network will be so composed as shown in fig 5.

V. UAVs/Drones Simulation Tests

In this section we explain the simulations that we have conducted in order to test the created network, composed of a set of nine drones, able to cover an area of about one square kilometer. We have performed many of simulations, varying the number of user in the area (50, 75 and 100 units). We have considered for the simulations the following performance parameters:

- jitter of audio and video streams;
- delay of audio and video streams;

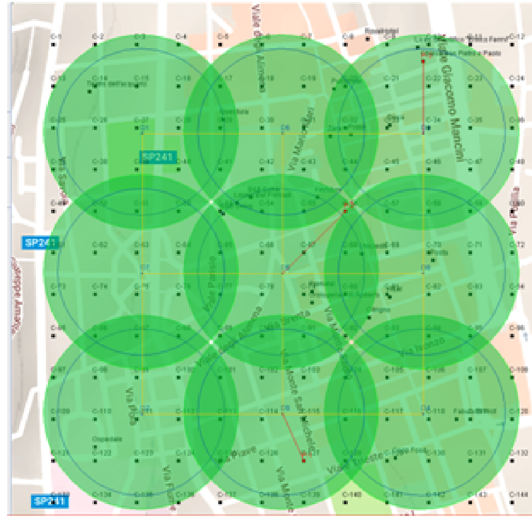

Fig. 5. UAVs/drones position in the considered area

- number of packets sent, received and lost;
- number of bandwidth requests made and refused;
- number of calls done;
- percentage of occupied bandwidth for each drone as regards the admission of calls.

The task of the network is to control the network behavior under a Link State protocol used for calculate the path between two users that want to communicate together. Simulation results show the trend of some parameters, such as sent and received packets, accepted and refused requests of bandwidth, delay of the two typologies of streaming. These parameters allow to evaluate the goodness of the proposed simulator, in which we have varied some ingress parameters. In particular, figure 6 shows that the number of packets, sent and received, increases with the number of people and that the number of lost packets is very low. Figure 7 shows the number of calls done and refused requests, varying the number of user between 50 and 100. It is possible to note how the number of bandwidth requests increases with the number of people and how, therefore, the number of calls done and the number of bandwidth requests refused will increase as we expect from the behavior of the network. Figure 8 analyses another aspect of the system, it shows the level of occupancy of each drone in terms of occupied bandwidth percentage. The drones 3 and 6 are those with the highest occupancy rate, due to a greater concentration of PoIs in the area covered by them. Furthermore, it can be seen how the percentage of bandwidth increases as the number of people increases. Finally, in the figures 9 and 10 it is possible to view the delays in both multimedia considered traffics, video and audio calls. Figure 9 shows the delay in user communications that consider VoIP multimedia traffic. Figure 10 presents the delays, minimum, mean and maximum for video traffic. The figures show delays in line with the typical delay of these typologies of multimedia traffics.

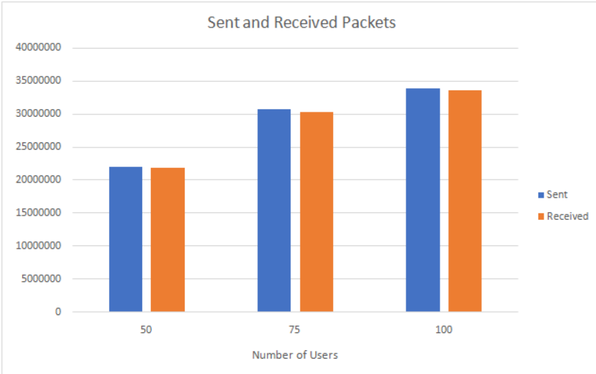

Fig. 6. Sent and received packets vs number of users

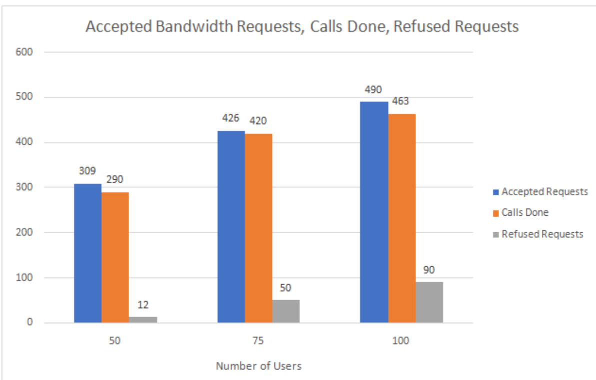

Fig. 7. Accepted bandwidth requests, calls done, refused requests vs number of users

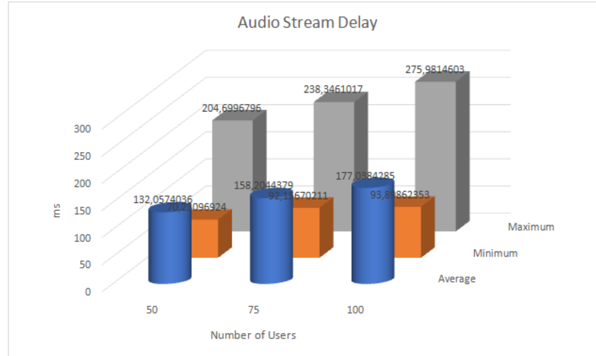

Fig. 9. Audio stream delay (min, medium, max) vs number of users

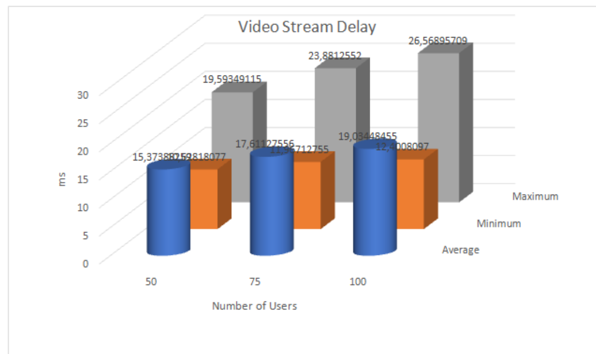

Fig. 10. Video stream delay (min, medium, max) vs number of users

VI. Conclusions

In this paper we proposes a new UAVs/drones simulator environment, created in Java. The software simulator can be useful for analyzing different aspects of the so called FANET. In this work we deal with the temporary communication possibility given by these new device, that is a very important research topic of these last years. This aspect is very important in many cases, first of all in emergency situations when it is important to guarantee efficient communications in the considered area. The proposed simulator is created in order to simulate different scenarios and cases of study, where users need to communicate with each others. The performance evaluation of the network with a Link State protocol (for finding the better path between users that communicate), considering multimedia traffic, such as video and audio streaming, is presented. We have simulated a team of drones able to cover a specif area where the considered footprint and human mobility models have been taken into consideration.

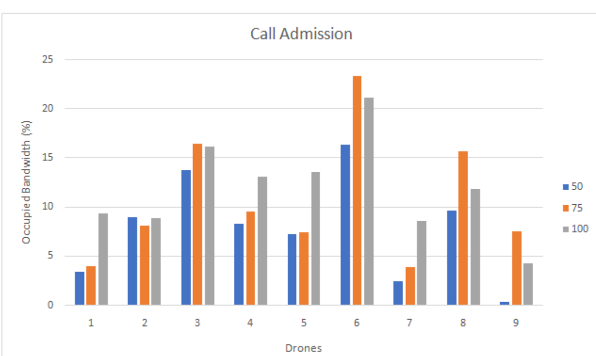

Fig. 8. Number of call admission vs drone for different number of users

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