Analysis of coverage and capacity limits for UAVs operating in ad-hoc networks

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Abstract **— The main objective of this dissertation is to develop a model for the analysis of coverage extension and capacity limits for UAVs operating in ad-hoc networks with a spatial distribution that fits the missions considered: targets collaborative search and tracking in maritime environment (where linear distribution is considered) and formation flight for detection of external threats to ship columns (where circular distribution is considered). The implemented model allows to obtain the maximum range of the network, while analysing the input parameters such as the height of the terminals, transmission rate, propagation model data and communication system (SC) features. In addition to the range imposed by the SC, components such as the UAVs' autonomy and the maximum distance in line of sight are also analyzed. Video transmission, by one or more UAVs of the network, is the service considered in this work. Results show that in the linear/circular scenario, the range of the network increases/decreases with the total number of UAVs used. Also, the lower the video transmission rate and the number of graphic information sources, the larger is the maximum distance allowed. For a network of 4 UAVs, with a video source of 2 Mbps, a range of 208.88 km and 69.78 km was obtained for the linear and circular scenario, respectively, and for a case in which all UAVs transmit video, the result obtained was 170.08 km and 40.02 km for the linear and circular case, respectively.**

UAV ad-hoc networks; Coverage; Capacity; Video transmission; Propagation over sea.

I. INTRODUCTION

To guarantee the independence and sovereignty of a State, it is crucial to safeguard its interests and to ensure its security. Portugal has a Search and Rescue (SAR) area that corresponds to about 63 times the national territory [1]. In this regard, ensuring maritime space security is one of the national security priorities [2]. In the aviation industry, an increasing effort has been made to replace the crews operating on board aircraft and are at increased risk by remote control of unmanned aircraft from the ground station. It is in this sense that the concept of Unmanned Aerial Vehicle (UAV) arises, being one of its purposes to carry out missions of short and/or long duration without endangering the human life. Currently, in the field of maritime operations, UAVs are used in missions such as SAR, maritime surveillance and patrolling, pollution detection and illegal fishing [4].

The use of a single UAV has been replaced by the use of several UAVs. An ad-hoc network of UAVs is considered to be one in which UAVs and/or GCS can be used as relay nodes [5]. In military surveillance and reconnaissance missions, SAR and target detection and tracking, UAVs are typically used to collect information from a target and transmit them to the GCS. In a system with only one UAV, the coverage area is limited due to restrictions inherent in the scope of communications, and the use of systems with several UAVs is a possible solution to this problem.

The FA has been participating in the development and investigation of UAV systems (UASs), with the intention of using them in a maritime operational environment. The communications system (SC) currently used in the UAV systems of the Air Force Academy Research Center (CIAFA) does not allow the direct sharing of data between UAVs. To enable the use of ad-hoc networks of UAVs with retransmission in missions of interest to the FA, the process of acquisition and installation of radios with IP connectivity in both the UAVs and the GCS is currently underway. Thus, the objective of the Dissertation was to develop a model that would allow analysing the extension of coverage and capacity limits in the ad-hoc networks of UAVs, allowing an adequate sizing of the network. The model, when implemented, allows the dimensioning of an ad-hoc network of UAVs corresponding to two operating scenarios, target tracking missions (linear formation of UAVs) and detection and protection of forces (circular formation of UAVs) maritime.

In Chapter II the state of the art is presented. Chapter III describes the model and its implementation. This chapter describes the UAV system considered and presents the scenarios of operation, development and implementation of the model. Chapter IV presents an analysis of the results obtained. Chapter V is intended for the conclusions regarding the work carried out.

II. STATE OF THE ART

The effect of MPCs on an A2G connection at 2.4 GHz and 5 GHz at an altitude of 100 m and 600 m was simulated in [6], analysing the power at the reception. Simulations of the range of transmission systems were also made using suitable propagation models, based on reception power and sensitivity of the equipment, for operating altitudes of 150 m and 250 m. In addition to the simulations, [6] presents results of the flight tests performed on the sea at 600 m altitude, in which the SC of the Piccolo autopilot link (2.4 GHz) is tested, recording the RSSI (Received Signal Strength Indicator), which corresponds to the power of the received signal, and ACK Ratio (Acknowledgement Ratio), which refers to the percentage of packets received in relation to those sent. In the flight tests on the sea, [6] observes two main effects in terms of propagation: the multipath, which gives rise to the constant signal variation (RSSI) that occurs for the whole duration of the flight; and the slow fading, which can be seen in the difference in power observed at the beginning and at the end of the flight. In [6] it is also observed that when considering the free space propagation model (FSPL) in computing the reach of the communications system, the attenuation in propagation in real situation is always greater than that of the model in question and, as such, the range of the connections must always be lower than that of the free space.

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A radio-propagation channel model for communications between UAVs during emergency scenarios at the 2.4 GHz frequency is developed in [7]. In this study, the author analyses signal losses due to MPCs caused by reflections on the ground, fading, Doppler effect, and dispersion. The channel is modelled for different operating altitudes of the UAVs, 150 m and 500 m.

In [8] an analysis of the scalability of FANET networks is presented through 3D flight simulations on two types of terrain: smooth and rough, where UAVs maintain a constant altitude above the ground. In this way, the altitude of the UAVs will suffer greater variations in the case of the rugged terrain, reason why greater losses of a signal in this type of terrain are expected. The authors consider the model of propagation in free space and use of antennas whose beam can be directed, concentrating the largest amount of energy in a given region. However, a small part of the energy is dissipated in other directions. The authors analyse the interference caused by the neighbouring UAVs, arriving at the conclusion that the smaller the beam opening at -3 dB, the smaller the impact caused by neighbouring nodes and, consequently, the greater number of simultaneous A2A connections allowed.

In [9] the impact of FANET size on the transmission rate, power consumption and reach of the connections is evaluated. The authors conclude that as the number of UAVs in the network increases: the value of the useful transmission rate per unit of energy decreases exponentially, which is due to the fact that the available bandwidth (BW) in the network decreases with the increase in the number of nodes; the maximum range of the connections (network coverage) increases linearly; and the delay in propagation, jitter, shows an exponential increase, which is mainly due to the fact that the addition of each node in the network causes an increase in the possibility of failure in the communications system.

In [10] the Feedback Communications Control (FCC) module is presented for UAVs that can evaluate the Quality of Service (QoS) associated with the connections of these systems, considering the restrictions imposed by communications in maritime environments and the requirements inherent to the missions of SAR. In this study, the problem of maintaining a connection with a given user-defined QoS between a GCS and a UAV is analysed, which has the function of retransmitting the signal from the mission-executing UAV to the GCS during the maritime operations. The authors propose a feedback strategy, which consists of commanding and optimizing the mobility of the relay UAV and adapting the algorithm to the desired QoS. The performance of the strategy proposed by [10] is illustrated through computational simulations and experimental results. In this study, QoS is associated with the balance between transmission rate and energy consumption. The energy consumption is estimated considering the momentum of the UAV, despising the electronic equipment on board. Thus, the control of this parameter is done acting on the speed of the UAV. Regarding the estimation of the transmission rate, this is a computationally complex task, since it depends on several external factors such as the antennas used and their orientation or the meteorological conditions. To obtain an approximation of the transmission rate, the authors use the values of transmission power, receiver sensitivity, emitter and receiver gain and modulation used in the specifications of the technology used, in this case, TP-LINK WN-722 2.4 GHz IEEE802.11b / g / n. To test the algorithm module to estimate the transmission rate, a field test was performed in which two IEEE802.11b / g / n TL-WN722N devices were used, one in the GCS and the other in a UAV to fly over an altitude of 40 m above the ground. The main objective of the test was to observe the difference between the recorded transmission rate and the estimated values through the calculations performed using the parameters of the datasheet and considering the free space propagation model. The results of the performed tests also show that the transmission rate is greater as the distance between the sender and the receiver is smaller.

III. Model Development and Implementation

A. *UAV system under study*

In this Dissertation, reference is made to the same UAV system used in the scope of the Seagull project, consisting of the aerial platform - the ANTEX X02 Extended UAV; by two stations, which together constitute the GCS, one of C2 (ETC2), whose task is to control and monitor the UAV onboard subsystems, and another one of the payload (ETP), through which the mission data are monitored.

The ANTEX-X02 Extended, shown in Figure 1, consists of several systems, which work in an integrated manner, such as structural, propulsion, communications, power, payload, and secondary and primary flight systems.

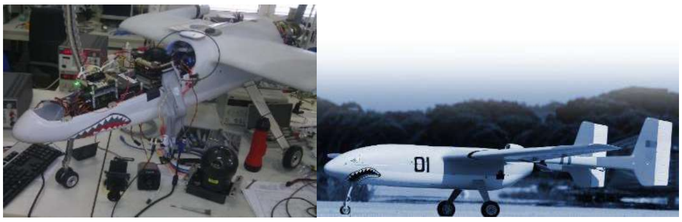

Figure 1 – ANTEX-X02 Extended UAV (extracted from [12]).

The system that controls the deflection of the UAV's flight surfaces according to the navigation references is the Piccolo autopilot, which communicates with the sensors and other subsystems on board through the C2 (SEC2) embedded system, to which it is connected by a serial communication port. The UAV trajectory is controlled by SEC2, which provides Piccolo with navigational references based on the position of the UAV and the information processed by the onboard sensors, provided by the onboard payload system (SEP) [11].

The link between the UAV and the terrestrial segment is typically established through a communications link in LOS in the UHF band and (depending on the mission) a satellite link (SATCOM).

UHF communication is made between 2.4000 GHz and 2.4835 GHz using a MicroHard Systems modem model MHX-2400 with a transmission power between 10 mW and 1 W. On board the ANTEX-X02 Extended an omnidirectional antenna is installed, thus ensuring communication with the GCS regardless of the orientation of the UAV, and a parabolic antenna with a gain of 24 dBi and a horizontal and vertical beamwidth of 10° and 14° respectively is used in the GCS. With the configuration described above, and in LOS, it is possible to obtain connections with a range up to 40 km [11]. The video transmission is performed through a dedicated and unidirectional connection. The transmitter, installed in the UAV, has the function of acquiring, digitizing, recording, modulating and transmitting the signal to the receiver, which is installed in the GCS. The onboard equipment allows the emission power to be varied between two levels, 60 or 250 mW, a BW of 8.7 MHz and, if necessary, the coupling of an amplifier which increases the power transmitted to 1 W.

The present SC does not allow the operation of the UAVs in ad-hoc networks. The C2 message exchange and telemetry equipment, while admitting configurations valid for ad-hoc networks because it is integrated into the Piccolo autopilot, implies limitations in its configuration. The closed solution provided by the manufacturer does not allow the exchange of messages between UAVs. The inability of UAVs to communicate in ad-hoc networks limits their operation in more complex missions.

In order to overcome this problem, we intend to purchase and install Microhard Pico Digital Data Link 2450 (pDDL2450) radios. These radios allow transmission rates higher than 20 Mbps, are accompanied by configuration software, which allows you to select different transmission power values and the modulation used. Considering the characteristics of the pDDL2450 radio, it is suitable for more complex applications, such as the flow of graphical information in an ad-hoc network of UAVs. With its implementation in the UAS of the FA it is hoped to obtain on the one hand a redundant connection for sending messages of telemetry and C2, and on the other a connection multi-jumps that supports a flow of graphical information, between the GCS and a UAV.

Figure 2 shows a simplified schematization of UAS SC. As shown in the block diagram, the currently existing SC is highlighted in green, consisting of a dedicated link to send graphics information, from the aerial platform to the GCS, and the MHX-2400 radio, integrated in the autopilot Piccolo, for the exchange of CNPC data between the ground station and the UAV, the telemetry messages being represented by a black unidirectional arrow (A2G link) and C2 with a red unidirectional arrow (G2A link). In turn, the dedicated video transmitter is underlined to magenta. Given the limitations of the dedicated video transmitter compared to the characteristics of the pDDL2450 radios, it is planned to be replaced by the latter in future CIAFA UAV missions. The SC that is intended to be implemented (for which this Dissertation contributes significantly) is highlighted in blue.

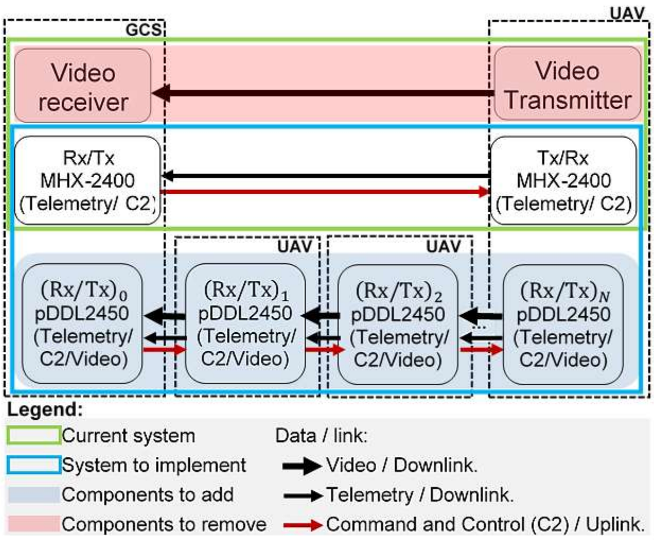

Figure 2 – Current communication system and the one to be implemented.

For antennas, the TL-ANT2405CL on the aerial platforms and the TL-ANT2424B and OD12-2400 in the GCS of the online and circular scenario, respectively, are used. The antenna installed in the UAVs is omnidirectional and has a gain of 5 dBi. The one used in the GCS of the scenario in which the UAVs are arranged linearly is directional and allows a gain of 24 dBi and that used in the GCS of the circular scenario is omnidirectional and has a gain of 12 dBi.

In addition to the maximum scope imposed by the SC, one also considers the maximum distance imposed by the autonomy of the UAV. It should be noted that considering any realistic mission scenario using a UAV, it is necessary to ensure that the sum of round trip and mission execution times does not exceed the UAV's autonomy time regardless of the range of its SC see Equation (1)). In this context, a safety margin should also be considered when calculating the time for the UAV's autonomy.

$$t_{aut\,[\mathrm{h}]} = 2 \times t_{alvo,máx\,[\mathrm{h}]} + t_{exec\,[\mathrm{h}]} + t_{m\,[\mathrm{h}]} \tag{1}$$

where:

- t_{alvo}: time taken to travel between the GCS and the target;
- t_{aut}: UAVs' autonomy;
- t_{exec} : mission execution time;
- t_m: safety margin time.

Knowing the cruise speed characteristic of the UAV and the maximum time available for the path between the GCS and the target, which is obtained by manipulating (1) and given by (2), we obtain the maximum network range imposed by autonomy of the UAV, $d_{máx,AU}$, given by (3).

$$t_{alvo,máx\,[\mathrm{h}]} = \frac{1}{2}\left(t_{aut\,[\mathrm{h}]} - t_{exec\,[\mathrm{h}]} - t_{m\,[\mathrm{h}]}\right) \tag{2}$$

$$d_{máx,AU\,[\mathrm{km}]} = v_{[\mathrm{km/h}]} \times t_{alvo,máx\,[\mathrm{h}]} \tag{3}$$

where:

- v: UAVs' cruise speed;
- $t_{alvo,máx}$: maximum time available for the course between the farther target and the GCS.

Based on the capacity of the fuel tank and the average fuel consumption, we obtain the estimated autonomy time for a given mission, given by (4).

$$t_{aut\,[\mathrm{h}]} = \frac{V_{[\mathrm{l}]}}{C_{[\mathrm{l/h}]}} \tag{4}$$

where:

- V: UAVs' fuel tank volume;
- C: UAVs' average fuel consumption, measured for a given mission.

The UAV is equipped with a generator and its power system allows it to supply up to 100 W continuously to the onboard systems, thus ensuring the 2.4 W required for the operation of the SC. The above average consumption of 1.1 l/h already takes into account the electrical consumption of the onboard systems.

B. Scenarios development

In this dissertation, two operating scenarios are evaluated, both linear (Scenario L) and circular (Scenario C), both of which correspond to the maritime environment, with links in LOS.

The first scenario considered corresponds to the follow-up of a certain target in a maritime environment, as in the case of a shipwreck, or maritime patrol, presenting a hierarchical structure. In this case, the UAVs are positioned along the line connecting the target to the GCS, in order to retransmit information sent by the UAV that has the function of collecting information about the castaway, to the GCS that is located at an aerodrome, together with the coast. It is considered that the UAV farthest from the GCS after reaching the point of interest, is in autonomous target tracking mode, sending graphics information to the GCS. The remaining nodes retransmit information from the UAV further to the GCS.

UAVs fly at an altitude that can vary between 50m and 500m, exchanging telemetry messages and C2 with GCS. Both the telemetry and C2 data occupy 300 bytes and are sent with a refresh rate of 10 Hz, which translates to a transmission rate of 0.024 Mbps. An example of the described scenario is shown in Figure 3, wherein a set of N UAVs is positioned along the line connecting the target to the GCS, at the same altitude*,* h, relative to the Mean Sea Level (MSL).

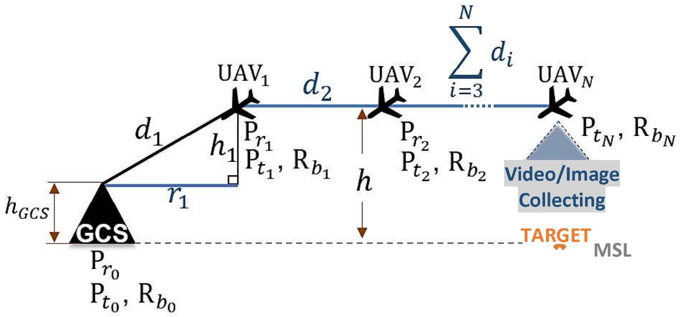

Figure 3 – Linear formation of *N* UAVs.

The function of the node farthest from the GCS, UAV_N, is to collect information (images/video) on the target and transmit them to the nearest UAV, UAV_{N-1}, the latter corresponding to the retransmitter node. This, after receiving the data of the UAV_N, transmits them to the UAV_{N-2}. The process is repeated until the UAV closest to the GCS, UAV_1, which has the function of transmitting the data to the GCS. Note that in this example only the extreme UAV, UAV_N, transmits graphics information of the target of interest. All other UAVs simply relay this information. However, in addition to the example above, there may arise situations where, along with the line connecting the UAV_N to the GCS, there is more than one target, thus there is more than one UAV to transmit video/images, being that at the limit there are *N* sources of graphical information.

For the graphic information transmission, there are two possibilities:

- Raw transmission, frame-by-frame, from a PAL (720x576) x 3-channel x 8-bit/pixel image, with an update rate of 1 frame every 5 seconds, corresponding to a transmission rate of approximately 2 Mbps;
- Continuous transmission of a video stream with a transmission rate of up to 4 Mbps.

In this operation scenario, we intend to determine the maximum mission range, which corresponds to the distance between the farthest UAV and the GCS. It should be noted that this measure also determines the area of the search (offshore, from the GCS) that can be allocated on a given mission, given the number of UAVs available. On the other hand, given the limited BW for the transmission of information, the capacity of the transmission system used will be analysed in order to determine the absolute maximum range and its maximum number of UAVs to carry out this mission.

The second scenario considered in this Dissertation presents a distributed architecture, as shown in Figure 4.

In this scenario, a group of *N* UAVs moves in a coordinated fashion around a column of ships, at sea, following a circular reference path, whose centre coincides with the geometric centre of the set of vessels, which moves in solidarity with the column. It is intended that the radius of the circular reference path be as large as possible, to anticipate as much as possible a potential threat. The altitude, h, of the UAVs can vary between 50 m and 500 m. It is also considered that UAVs have homogeneous characteristics and that all nodes are at the same altitude in relation to MSL.

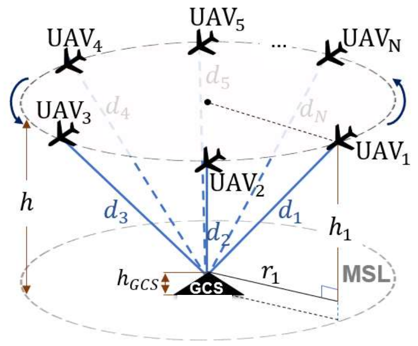

Figure 4 – Circular formation of *N* UAVs.

It is in the GCS, which is on board one of the ships, that the position references for each UAV are established and sent, so as to ensure an adequate distribution of the UAVs around the ship 's column. Regarding the CNPC data, each UAV has a matrix that is updated at each moment with the information sent by the GCS of the current position of each of the UAVs and their respective reference. The exchange of this data can be performed directly between the UAV and the GCS, or by jumps, using other UAVs as relays. It is considered that the GCS must be able to establish a bidirectional connection with all the UAVs simultaneously, in order to send C2 data and receive its telemetry along the circular path. The transmission rates associated with the data flow for Scenario C are identical to Scenario L.

It should be noted that in the example considered it is assumed that the ship in which the GCS is located coincides with the geographical centre of the reference circumference and is thus at the same distance from all the UAVs that make up the network.

In this scenario, it is intended to calculate the maximum radius of the reference circle around the vessel column, considering the number of UAVs used, the modulation and characteristics of the SC.

C. *Model description*

The developed model, whose block diagram is illustrated in Figure 5, consists of scaling the maximum range of a network of UAVs that presents a spatial configuration identical to that of L or C Scenario.

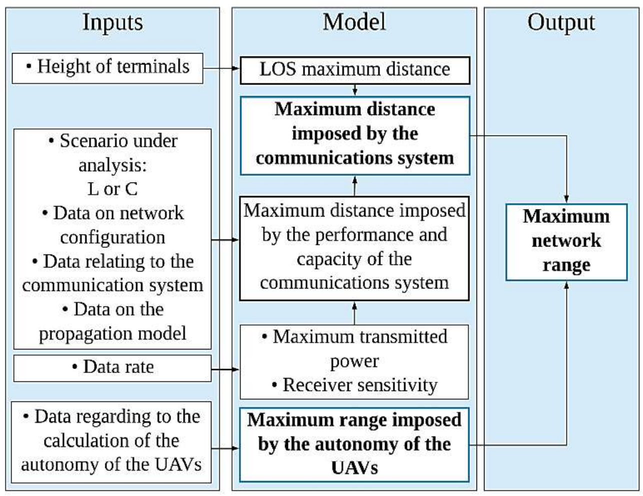

Figure 5– Model overview.

To correctly dimension the network, the following factors are analysed, which may limit its range:

i) Since the SC imposes the need for LOS between two terminals, the maximum LOS distance, $d_{máx,RH}$, given by (5) is considered.

$$d_{máx,RH\,[\mathrm{km}]} \cong 4{,}12 \times (\sqrt{h_{e\,[\mathrm{m}]}} + \sqrt{h_{r\,[\mathrm{m}]}}) \quad (5)$$

ii) Maximum network range imposed by the performance and capacity of the communications system, $d_{máx,DC}$, given by (6) and is the distance at which the power at the receiver corresponds to its sensitivity, is also considered.

$$d_{máx,DC\,[\mathrm{km}]} = 10^{\frac{L_{p,máx\,[\mathrm{dB}]} - 32{,}44 - 20\log(f_{[\mathrm{MHz}]}) - M_S}{20}} \quad (6)$$

iii) The autonomy, which depends on the capacity of the fuel tank and the average consumption. The maximum distance imposed by the autonomy, $d_{máx,AU}$, is given by (3).

Initially, the maximum distance imposed by the communications system, $d_{máx,DC}$, is calculated for each of the connections using the following input parameters:

- G_r: receiving antenna gain;
- G_t: transmitter antenna gain;
- M_S: safety margin considered in a path loss calculation;
- f: frequency;
- N: total link/UAV number;
- M: video sources number;
- Δf: bandwidth;
- R_b: link data rate.

Data rate is used to calculate the maximum transmitted power, $P_{t,máx}$, and the receiver sensitivity, $P_{r,min}$.

Then, for the same connections, the maximum distance in LOS is determined, $d_{máx,RH}$, the input parameters being the height of the receiver, h_r, and the height of the transmitter, h_t. For each of the connections, the limiting factor is chosen, that is, the lowest value between $d_{máx,DC}$ and $d_{máx,RH}$, resulting in $d_{máx,SC}$. Then, the $r_{c,máx}$ value is determined.

In calculating the maximum distance imposed by the autonomy of the UAVs, $d_{máx,AU}$, the input parameters are the volume of the fuel tank, V; the average fuel consumption, C; the cruise speed, v; the time required to carry out the mission, t_{exec}; and the safety margin time considered, t_m.

The maximum network range, d_L to the Scenario L and d_C to the Scenario C, is determined by choosing the lowest of the values obtained for the maximum range of the network analysing communications system, $r_{c,máx}$, and the one was obtained taking into account the autonomy of the UAVs, $d_{máx,AU}$.

Steps for calculating the coverage and capacity of Scenarios L and C are as follows.

Linear UAV formation:

- Step L1: knowing the transmission power and the gain of the transmitter, the sensitivity and gain of the receiver, and the safety margin considered, the maximum value of the path loss, $L_{p,máx,1}$, regarding to the first link, d_1, are calculated using:

$$L_{p,máx[\mathrm{dB}]} = P_{t,máx[\mathrm{dBm}]} + G_{t[\mathrm{dBi}]} - P_{r,min\,[\mathrm{dBm}]} + G_{r[\mathrm{dB}} \quad (7)$$

- Step L2: the maximum range imposed by the SC's performance of the respective connection is determined, $d_{máx,DC,1}$, by (6).
- Step L3: knowing the UAVs' height, $h \equiv h_e$, and GCS's height, $h_{GCS} \equiv h_r$, regarding to the MSL, the maximum LOS distance is calculated, $d_{máx,RH,1}$, by (5).
- Step L4: the maximum range imposed by the SC between the terminals is determined, $d_{máx,SC,1}$, choosing the lowest value from those calculated in Steps L2 and L3, as given:

$$d_{max,SC,1\,[\mathrm{km}]} = \min\{d_{máx,DC,1\,[\mathrm{km}]}, d_{máx,RH,1\,[\mathrm{km}]}\} \quad (8)$$

- Step L5: the coverage associated with the link between the GCS and the *backbone* UAV, r_1, is determined using:

$$r_{1\,[\mathrm{m}]} \cong \begin{cases} d_{máx,SC,1\,[\mathrm{m}]} & , d_{máx,SC,1} \geq 100h \\ \sqrt{{d_{máx,SC,1\,[\mathrm{m}]}}^2 - {h_{[\mathrm{m}]}}^2} & , caso\ contrário \end{cases} \quad (9)$$

- Step L6: knowing the transmission power, sensitivity and gain of the SC installed in the UAVs, and the safety margin considered, the path losses associated with the A2A links, $L_{p,máx,i}$, $i = 2, \ldots, N$, are calculated by (7).
- Step L7: the maximum range for the remaining (N-1) A2A connections of the network, $d_{máx,SC,i}$, are calculated following steps from L1 to L4.
- Step L8: assuming that for $i = 2, \ldots, N$, $r_i \approx d_i$, by adding the distances obtained in Steps L3 and L7, the coverage associated with Scenario L, $r_{c,máx,L}$, is obtained using:.

$$r_{c,máx,L\,[\mathrm{km}]} \cong r_{1\,[\mathrm{km}]} + \sum_{i=2}^{N} d_{máx,SC,i\,[\mathrm{km}]} \quad (10)$$

- Step L9: considering that all UAVs have the same characteristics, the maximum range of the network imposed by the autonomy of the UAVs, $d_{máx,AU,L}$, is obtained by (3).
- Step L10: the maximum network range, d_L, is determined by choosing the lowest value from those calculated in Steps L8 and L9, as given:

$$d_{L\,[\mathrm{km}]} = \min\{r_{c,máx,L\,[\mathrm{km}]}, d_{máx,AU,L\,[\mathrm{km}]}\} \quad (11)$$

Circular UAV formation: assuming all UAVs use the same SC and have the same structural characteristics and other systems used on board, the network coverage of Scenario C is obtained by performing the following steps.

- Step C1: taking UAV_1 as reference, e knowing the transmission power and the gain of the transmitter, the sensitivity and gain of the receiver, and the safety margin considered, the maximum value of the path loss, $L_{p,máx,1}$, regarding to the first link, d_1, are calculated using (7).
- Step C2: the maximum range imposed by the SC's performance of the respective connection is determined, $d_{máx,DC,1}$, by (6).
- Step C3: knowing the UAVs' height, $h \equiv h_e$, and GCS's height, $h_{GCS} \equiv h_r$, regarding to the MSL, the maximum LOS distance is calculated, $d_{máx,RH,1}$, by (5).
- Step C4: the coverage associated with the link between the GCS and UAV_1, $d_{máx,SC,1}$, is determined choosing the lowest value from those calculated in Steps C2 and C3, as given in (8).

- Step C5: the coverage for the Scenario C, $r_{c,máx,C}$, is determined using:

$$r_{c,máx,C\,[\mathrm{m}]} \cong \begin{cases} d_{máx,SC,1\,[\mathrm{m}]} & , d_{máx,SC,1} \geq 100h \\ \sqrt{{d_{máx,SC,1\,[\mathrm{m}]}}^2 - {h_{[\mathrm{m}]}}^2} & , caso\ contrário \end{cases} \quad (12)$$

- Step C6: considering that all UAVs have the same characteristics, the maximum range of the network imposed by the autonomy of the UAVs, $d_{máx,AU,C}$, is obtained by (3),
- Step C7: the maximum network range, d_C, is determined by choosing the lowest value from those calculated in Steps C5 and C6, as given:

$$d_{C\,[km]} = min\{r_{c,máx,C\,[km]}, d_{máx,AU,C\,[km]}\} \quad (13)$$

The network's capacity is analysed as following:

In the **linear scenario**, for the UL connection, GCS sends C2 data to all UAVs from the network and, regarding to the DL connection, receives telemetry data from *N* UAVs and graphical information of the target from the selected *M* sources, with *M* ∈ [0, *N*]. Each UAV also sends and receives position and reference data, $R_{b,P,}$, of the remaining UAVs. The transmission rate of these data is significantly lowest then the transmission rate corresponding to the telemetry, $R_{b,T}$, considering in this study a ratio of 1% between the two parameters.

In the **circular scenario**, as in the in-line configuration, all UAVs receive C2 messages from the GCS (UL), and send telemetry data to the GCS (DL). In addition, each UAV sends and receives position and reference data of the remaining UAVs, where GCS may be used as a relay node. Thus, considering that there are Q UAVs to use GCS as a relay, the GCS will have to receive and send $Q \times R_{b,T}$ of position and reference data. For the graphics information, the GCS selects the *M* video sources, which can vary between 0 and *N*.

Table 1 shows the expressions for the UL and DL bond capacity requirements for the two operating scenarios under study.

Table 1 – Capacity requirements of L and C Scenarios.

Link	Scenario	Data rate required [Mbps]
UL	L	$N \times R_{b,C2}$
	C	$N \times R_{b,C2} + Q \times R_{b,P}$
DL	L	$N \times R_{b,T} + M \times R_{b,vídeo}$
	C	$N \times R_{b,T} + M \times R_{b,vídeo} + Q \times R_{b,P}$

where:

- $R_{b,C2}$: C2 data rate;
- Q : number of UAVs using a GCS as a relay node for exchange of position and reference data in Scenario C;
- $R_{b,T}$: telemetry data rate;
- $R_{b,vídeo}$: video data rate.

In the developed model, CNPC data are considered and the position and reference data are neglected.

The expression (14) is used to calculate the rate associated with the uplink, $R_{b,UL}$, and (15) is used to calculate the rate associated with the uplink, $R_{b,DL}$.

$$R_{b,UL\,[\mathrm{Mbps}]} \begin{cases} = N \times R_{b,C2\,[\mathrm{Mbps}]} , & L \\ \cong N \times R_{b,C2\,[\mathrm{Mbps}]} , & C \end{cases} \quad (14)$$

$$R_{b,DL\,[\mathrm{Mbps}]} \begin{cases} = N \times R_{b,T\,[\mathrm{Mbps}]} + M \times R_{b,vídeo\,[\mathrm{Mbps}]} , L \\ \cong N \times R_{b,T\,[\mathrm{Mbps}]} + M \times R_{b,vídeo\,[\mathrm{Mbps}]} , C \end{cases} \quad (15)$$

Considering that the data rate associated with the DL, $R_{b,DL}$, is the limiting factor, since it has the highest data rate, and that the SC installed in the UAVs and the GCS is identical, it is assumed that there will be no capacity problems from the point of view of the UL connection. Thus, in the analysis presented, only DL binding is considered. In the capacity analysis, the condition given by (16) must be satisfied.

$$R_{b,cap\,[\mathrm{Mbps}]} \geq R_{b,DL\,[\mathrm{Mbps}]} \quad (16)$$

where:

- $R_{b,cap}$: SC's capacity.

In this study the capacity of the Microhard pDDL2450 technology is considered, where the user can select the BW, which can be 2, 4 or 8 MHz and its modulation, which can be BPSK 1/2, QPSK 1/2, QPSK 3/4, 16QAM 1/2, 16QAM 3/4, 64QAM 2/3, 64QAM 3/4 or 64QAM 5/6. Each modulation corresponds to a certain data rate which, which corresponds to different values of sensitivity and maximum transmission power. The higher the vel modulation schemes correspond to higher sensitivity values. And the lower the BW of the channel, the more robust the system, because it allows to detect signals that have less power.

To implement the model, the approximate expressions for the maximum transmission power and the sensitivity, given by (17) and (18), respectively, were deduced as a function of the data rate, which in turn depends on the BW and modulation scheme selected.

$$P_{t,máx\,[\mathrm{dBm}]}(R_{b\,[\mathrm{Mbps}]}, \Delta f_{[\mathrm{MHz}]}) = $$
$$= \begin{cases} -0{,}618R_b + 30{,}9 , & R_b \in [0{,}78; 6{,}5],, & \Delta f = 2 \\ -0{,}287R_b + 30{,}8 , & R_b \in [1{,}5; 14], & \Delta f = 4 \\ -0{,}145R_b + 30{,}9 , & R_b \in [3; 28], & \Delta f = 8 \end{cases} \quad (17)$$

$$P_{r,min\,[\mathrm{dBm}]}(R_{b\,[\mathrm{Mbps}]}, \Delta f_{[\mathrm{MHz}]}) = $$
$$= \begin{cases} 3{,}35R_b - 104 , & R_b \in [0{,}78; 6{,}5], & \Delta f = 2 \\ 1{,}62R_b - 102 , & R_b \in [1{,}5; 14], & \Delta f = 4 \\ 0{,}805R_b - 98{,}4 , & R_b \in [3; 28], & \Delta f = 8 \end{cases} \quad (18)$$

To test the radios under study, bench tests were performed using the iPerf program to inject data into one of the terminals and evaluate the BW of the channel. As can be seen in Figure 6, three radios pDDL2450 were used: R1, connected to the HP portable computer, were used as GCS; R2, with the function of relaying node; and R3, connected to a Toshiba laptop, through which data were injected, to allow testing of network performance. The three radios are powered with 12 V ± 0.15, using a voltage generator.

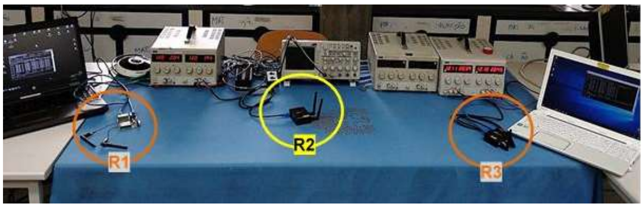

Figure 6 – Configuration of the experimental tests performed on pDDL2450 radios.

The direct link (from R3 to R1) and, then, the link with a relay, adding the R2 radio as the relay node, was tested. With the tests carried out, it was observed that when adding a relay node, half-duplex operation was forced, reducing the BW of the system to half, which has an impact on the results in the Scenario L. Thus, the expressions (19) and (20) were deduced to be used in the study of the linear scenario.

$$P_{t,máx\,[dBm]}\left(R_{b\,[Mbps]}, \Delta f_{[MHz]}\right) = \\ = \begin{cases} -1{,}24R_b + 30{,}9\,, & R_b \in [0{,}39; 3{,}25]\,, \quad \Delta f = 2 \\ -0{,}574R_b + 30{,}8\,, & R_b \in [0{,}75; 7], \quad \Delta f = 4 \\ -0{,}145R_b + 30{,}9\,, & R_b \in [1{,}5; 14], \quad \Delta f = 8 \end{cases} \quad (19)$$

$$P_{r,min\,[\mathrm{dBm}]}\left(R_{b\,[\mathrm{Mbps}]}, \Delta f_{[\mathrm{MHz}]}\right) = \\ = \begin{cases} 6{,}7R_b - 104\,, & R_b \in [0{,}39; 3{,}25], \quad \Delta f = 2 \\ 3{,}23R_b - 102\,, & R_b \in [0{,}75; 7], \quad \Delta f = 4 \\ 0{,}805R_b - 98{,}4\,, & R_b \in [1{,}5; 14], \quad \Delta f = 8 \end{cases} \quad (20)$$

IV. RESULTS ANALYSIS

A. General analysis

In this section, a general analysis of the results, obtained for the scenarios used in the model measurement phase (in which the values of several variables given by the implemented simulator were confirmed by the scientific calculation in a TI-nspire CX CAS calculator), is described.

For Scenario L and varying *N*, with h_{UAV} =50 m, h_{GCS} =3 m, *M*=1, Δf =8 MHz, G_{GCS} =24 dBi, G_{UAV} =5 dBi, M_S =3 dB and f=2,4 GHz, results presented in Figure 7 were obtained.

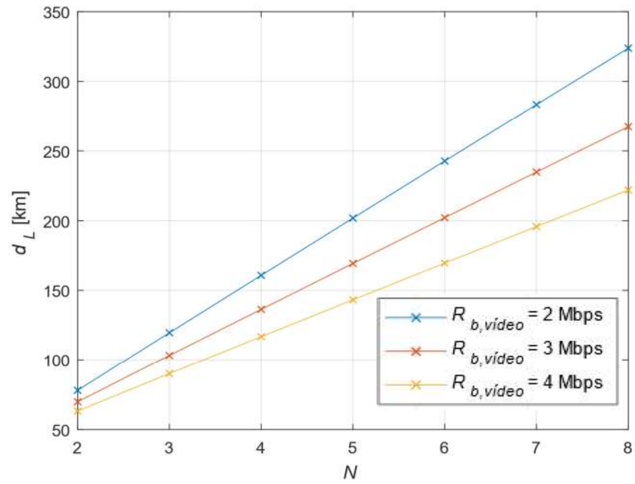

Figure 7 – Maximum network range as a function of *N* (L Scenario).

As it was expected, the lower the video bit rate, the greater the maximum network range. Also, with the addition of relay nodes in the network, the maximum range increases.

Figure 8 shows the maximum range as a function of the number of video sources, in a network with a total of 6 UAVs operating in a linear scenario.

As it was expected, when selecting a larger number of video sources, the network range decreases due to the data rate increase. Also, it is observed that the lower the video data rate, the greater the network range. For example, regarding do the 2 Mbps video data rate it is possible to have all UAVs being video sources. For the 3 Mbps video data rate it is only possible to select 4 video sources; and for 4 Mbps, 3 is the maximum number of *M*.

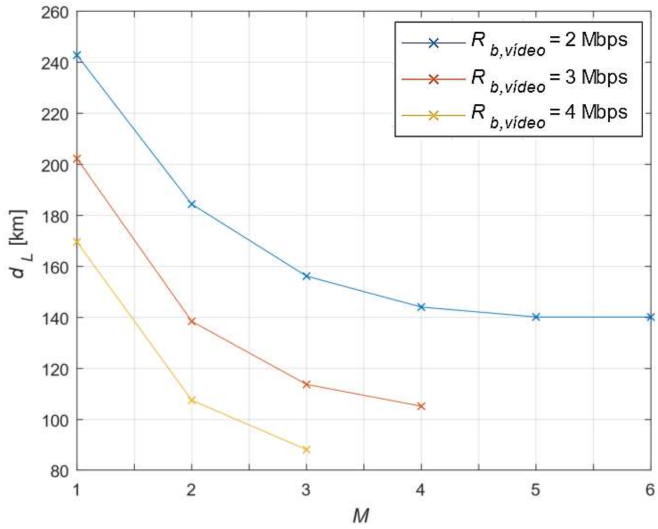

Figure 8 – Maximum network range as a function of *M* (Scenario L).

In a C Scenario, as it can be observed in a Figure 9 which was obtained using parameters from Tables 2 and 3, the maximum network range is as lower as higher is the number of video sources. Also, the higher the video data rate, the lower is the network range. For this simulation h_{UAV} = 400 m was considered.

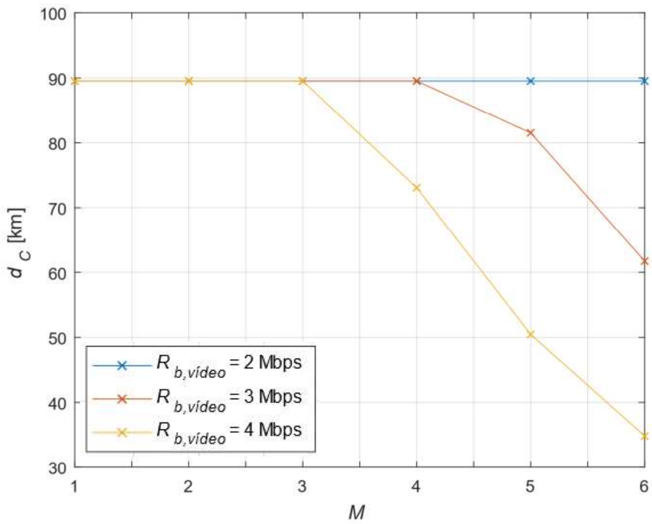

Figure 9 – Maximum network range as a function of *M* (C Scenario).

B. Realistic scenarios definition

For the linear scenario, GCS similar to the one used in the flight tests already carried out by CIAFA, in which a parabolic antenna TL-ANT2424B was used, located in the *Aeródromo Municipal de Torres Vedras* (39 ° 07'36.4 "N, 9 ° 22'45.4" W).

For the circular Scenario, a ships' column carrying out a mission that involves crossing the Atlantic Ocean, with a GCS in its centre, was considered.

Table 2 represents the parameters regarding to the autonomy of the UAVs, and Table 3 contains those referring to the SC.

Table 2 – UAVs' autonomy parameters.

V [l]	C [l/h]	t_{exec} [h]	t_m [h]	v [km/h]
Linear Scenario				
11	0.9	0.5	0.3	70
Circular Scenario				
7	1.1	1	0.3	70

Under these conditions and considering the highest modulation scheme (64QAM 5/6), the UAVs' maximum number, $N_{máx}$, is represented in Table 4.

Table 3 – SC's parameters.

h_{UAV} [m]	h_{GCS} [m]	Δf [MHz]	f [MHz]	$R_{b,T}$ [Mbps]	G_{UAV} [dBi]	G_{GCS} [dBi]	M_S [dB]
Linear Scenario							
200	40	8	2400	0.024	5	24	3
Circular Scenario							
50	15	8	2400	0.024	5	12	3

The values obtained for M = 1 are to demonstrate that the capacity is not a limiting factor in the network where only the extreme UAV transmits video. In a real situation, with the FA's resources it would not be feasible to operate with a network with more than 8 UAVs.

Table 4 – UAVs' maximum number, for 2 and 4 Mbps video, and M = 1 and N.

		$N_{máx}$			
$R_{b,vídeo}$ [Mbps]		2		4	
Scenario		**L**	**C**	**L**	**C**
M	1	500	1083	416	1000
	N	6	13	3	6

C. *Results for Linear Scenario*

The network's range with 2 and 4 Mbps video was analysed. The range imposed by the autonomy of the UAVs obtained was 399.78 km.

For the case where only the extreme UAV transmits video (M = 1), the results obtained are those represented in Table 5.

Table 5 – Results for M=1, $R_{b,vídeo}$ =2 or 4 Mbps (L Scenario).

N		4	5	6	7
Maximum range (imposed by SC) [km]	$R_{b,vídeo}$ = 2 [Mbps]	208.88	249.96	290.83	331.48
	$R_{b,vídeo}$ = 4 [Mbps]	164.74	191.27	217.64	243.90

In this case, the network's range is never limited by the UAVs' autonomy. For 2 Mbps video, there is an increase of, approximately, 40 km with the addition of a UAV in the network.

From the analysis performed for the extreme case, in which all UAVs are graphical information sources (M = N), the results obtained are those represented in Table 6.

For a 4 Mbps video transmission, using radios pDDL2450, the maximum number of video sources is 3. Thus, in the case where N = 4 was analysed the scenario in which the two farthest UAVs transmit 4 Mbps video, and the rest are 2 Mbps video sources. For the network where N = 5, it was considered that only the extreme UAV captures and transmits 4 Mbps video, with the remaining four UAVs being a 2 Mbps video sources. Note that the range associated with the 2 UAVs network is higher than the other configurations. This is due to the lower transmission rate of the total network flow (between the GCS and the backbone UAV) - 8 Mbps for N = 2 and 12 Mbps for N = 5.

Table 6 – Results for M=N, $R_{b,vídeo}$ =2 or 4 Mbps (L Scenario).

N		2	3	4	5
Maximum range (imposed by SC) [km]	$R_{b,vídeo}$ = 2 [Mbps]	126.06	152.86	170.08	160.11
	$R_{b,vídeo}$ = 4 [Mbps]	111.27	79.42	86.38	103.38

For 2 Mbps video transmission, unlike the previous analysis, in this case there is only an increase of, approximately, 20 km with the addition of a node in the network. This result is because there is a significant increase in total data rate with addition of UAVs. It requires a higher modulation scheme, increasing the receiver sensitivity and maximum transmitted power.

Regarding the range obtained for N = 4 and N = 5, it would not be expected that with the addition of a UAV, the maximum distance imposed by the SC would decrease. The justification for this result (and remembering that the maximum range imposed by the SC is determined taking into account both the radios' performance and the maximum LOS distance) is that, under the mentioned conditions, until N = 4 the factor that limits the connection between the GCS and the backbone UAV is the maximum LOS distance. For N = 5, all connections, including the 1st one, are limited by the performance and capacity of the SC.

By analysing the obtained results, it is observed that, even in cases where there are N video sources with high transmission rates, the estimated maximum distances allow to reach areas of interest (regions where there is a high incidence of marine accidents and higher density of traffic), with the possibility of FA's UAVs carrying out search and/or maritime surveillance missions.

D. *Results for Circular Scenario*

Considering N = 3, 4, 5 and 6, and assuming 2 and 4 Mbps video transmission, the results obtained for M = 1 and for M = N, ware those shown in Table 7 and 8, respectively.

Table 7 – Results for M=1, $R_{b,vídeo}$ =2 or 4 Mbps (C Scenario).

N		3	4	5	6
Maximum range (imposed by SC) [km]	$R_{b,vídeo}$= 2 [Mbps]	69.94	69.78	69.63	69.47
	$R_{b,vídeo}$= 4 [Mbps]	56.20	56.07	55.95	55.82

Table 8 – Results for M=N, $R_{b,vídeo}$ =2 or 4 Mbps (C Scenario).

N		3	4	5	6
Maximum range (imposed by SC) [km]	$R_{b,vídeo}$= 2 [Mbps]	48.27	40.02	33.17	27.50
	$R_{b,vídeo}$= 4 [Mbps]	26.77	18.44	12.70	8.45

In C Scenario the network's range decreases with the addition of nodes. Also, the higher the total data rate, the lower the range obtained. This is because, when using more UAVs, the total data rate increases, which leads to the receivers' sensitivity increasing.

It is also observed that the higher the number of video sources, the smaller the maximum network distance imposed by SC. For example, for $N = 6$, when only one node transmits 4 Mbps video, the estimated range is 55.82 km. For $M = N$, the estimated maximum distance decreases to 8.45 km. A decrease of, approximately, 85% (≈47.4 km) is observed.

Considering the mission in which it is intended to apply this type of UAVs networks (with circular formation), which corresponds to the forces detection and protection in marine environment, the results obtained are considered favourable, because most of the asymmetric attacks occurs near the target. Thus, the estimated maximum distances allow, with significant margin, to anticipate a ship columns threat.

V. Conclusions

The main objective of this work was to develop a model that allows to determine the maximum coverage associated with an ad-hoc networks of UAVs, analysing its capacity limits. The UAS from CIAFA was considered. Its SC is in the process of alteration, to allow the formation of ad-hoc networks of UAVs with relaying. Two operating scenarios were defined: L Scenario, which corresponds to the linear formation of UAVs, and C Scenario, in which the UAVs have a circular distribution.

The UAS considered has as aerial platform the ANTEX-X02 Extended UAV. The current SC used in these UASs does not allow its operation in ad-hoc networks of UAVs, since it always requires a direct link between the UAV and the GCS. Video transmission is performed through a dedicated unidirectional connection (UAV → GCS), and the exchange of C2 and Telemetry messages via an integrated radio on the Piccolo autopilot which, due to the closed solution, does not allow communications between UAVs. To overcome this problem, the process of acquiring and installing radios pDDL2450 with IP connectivity, in the UAVs and the GCS, is currently under way. The main objective of this process is to allow the formation of UAV ad-hoc networks, extending the operating limits of the current UAS. The radios under consideration operate in 2.402 GHz to 2.488 GHz frequency band and allow data rates up to 20 Mbps. The SC considered in this Dissertation imposes the existence of LOS between the terminals, so that the maximum LOS distance is considered. In addition, the autonomy of the UAVs is also considered.

The first scenario (L Scenario) corresponds to the patrolling or tracking of target in marine environment, presenting a hierarchical architecture in which the UAVs are distributed along a line that connects the patrol/target zone to the GCS. The GCS's location is considered to be near the coast. In this scenario it is possible to several UAVs having to capture video. Video can be transmitted frame-by-frame or as a streaming. Situations in which all UAVs collect video are regarding to the target search phase, which precedes the target tracking phase.

The second scenario considered (Scenario C) corresponds to the missions of forces detection and protection, in the maritime environment. In this scenario, UAVs move in a coordinated way around a ships' column, following a circular reference path. The circle's centre coincides with the geometric centre of the set of ships. As in the linear scenario, it is considered the possibility of several UAVs having to capture and transmit video. In this analysis, it was assumed that the GCS is in the boat that corresponds to the ships column's centre.

For both scenarios, was considered the same altitude for all operating UAVs (between 50 and 500 m, regarding to the MSL). It was also considered that all UAVs have the same SC and use identical antennas. The propagation model taken into account is FSPL, and a safety margin is added in the calculation of signal losses during its propagation. A directional 24 dBi antenna was used in a GCS of L Scenario, and a omni-directional 12 dBi one was considered for a GCS of C Scenario.

To dimension an ad-hoc UAV network with configuration identical to that of L or C Scenarios, a model was developed and implemented. Input parameters considered are: terminal height, data rate, data related with the propagation model, SC, the calculation of the UAVs' autonomy and the network's configuration, namely the number of UAVs used and the selected video sources. Based on the estimated expressions of maximum transmitted power and receiver sensitivity, as a function of the maximum data rate and channel capacity, the maximum distance imposed by the SC performance is calculated. Also, the range imposed by the maximum LOS distance and UAVs' autonomy are determined. Finally, with analysis of the three distances obtained, the maximum network's range is determined.

In L Scenario, the range corresponds to the distance between the farthest UAV and the GCS. This measure also corresponds to the target search region off the coast, from the GCS, which is possible to allocate in a given mission.

For C Scenario C, the range corresponds to the maximum radius of the reference circle around the ships' column, taking into account the number of UAVs used, the defined modulation and the characteristics of the considered SC. The circular radius is calculated based on the most charged connection (for example, if there is only one UAV transmitting video, the circular radius will be the distance corresponding to the connection between the GCS and this UAV).

To test the pDDL2450 radios, bench tests were performed Two tools were used: iPerf, that allows injecting data (where the user can define the BW associated with the data to be injected) in one of the terminals and evaluate the BW of the system; and TamoSoft, that provides a diagnosis of link performance in terms of data rate.

After conducting the first experimental tests to the radios, it was found that when using them as relays the half-duplex mode of operation was forced. Thus, in the L Scenario analysis it would only be possible to consider half the SC capacity presented in the radios' specifications. In the case of C Scenario, taking into account the location considered for the GCS, which is such that the distance to the GCS is identical from all the nodes of the network, it is considered the mode of full-duplex radios. Regarding the performance specifications of the radios, they allow the maximum BW of 8 MHz, and a transmission rate of 28 Mbps can be reached by defining a modulation scheme 64 QAM5/6, which corresponds to a maximum transmission power of 27 dBm and a receiver sensitivity of -76 dBm, in full-duplex operation mode. In half-duplex, the capacity of the radios reduces by half.

The pDDL2450 radios allow you to define a 2, 4 or 8 MHz BW, and modulation schemes between BPSK 1/2, QPSK 1/2, QPSK 3/4, 16 QAM 1/2, 16 QAM 3/4, 64 QAM 2/3, 64 QAM 3/4 or 64 QAM 5/6 can be chosen, for each of the BWs. Depending on the BW and modulation selected, there is a maximum capacity defined in the specifications given by the manufacturer. Based on these data, maximum transmitted power and receiver sensitivity expressions were inferred as a function of the data rate, for the half-duplex and full-duplex mode. These expressions were used in the implementation of the model, which corresponds to a simulator developed in the Matlab R2017a program, and that allows to scale the network in L and C Scenario.

Several scenarios were simulated by measuring the value of several variables and the results obtained using a TI-nspire CX CAS calculator were confirmed. Using the results obtained in this process, the maximum network range was simulated as a function of the number of UAVs used, for different video data rates. Also, the network's range as a function of number of video sources was analysed. In this analysis, it was observed that the range increases with the total number of UAVs and decreases with the addition of image/video sources. Also, the higher the video data the lower is the network's range.

The realistic scenarios were defined and analysed. For L Scenario, *Aeródromo Muncipal de Torres Vedras* was a location chosen for the GCS. It was considered UAV's distribution in line over the Atlantic Ocean, at a 200 m altitude regarding to the MSL. Under the conditions defined for this scenario, and assuming the higher BW and modulation scheme, the maximum number of UAVs in an ad-hoc network was determined: 500 UAVs for 2 Mbps video transmission, if only one video source is considered ($M = 1$), and 6 UAVs, if all nodes are considered to capture and transmit video ($M = N$); 416 UAVs for $M = 1$ and only 3 UAVs for $M = N$, considering 4 Mbps video transmission. It should be noted that the values obtained for $M = 1$ are to demonstrate that the capacity is not a limiting factor in the network where only the extreme UAV transmits video. In a real situation, with the FA's resources it would not be feasible to operate with a network with more than 8 UAVs.

The results regarding L Scenario were obtained considering the half-duplex mode operation. However, according to the manufacturer, it is anticipated that the next version of pDDL2450 radios will allow full-duplex use, even though they are used as relays, implying different results than those estimated in this study.

For the linear scenario, when $M = 1$, for 2 Mbps video transmission, the range varies between ~ 200 km and 340 km for a network with a total of 4 to 7 UAVs, respectively; and for 4 Mbps video, a range varies between ~ 150 km and 340 km for networks composed by 4 and 7 UAVs, respectively. In both cases, the network's range value is as higher as higher is the total number of UAVs. For the case where it was considered that all UAVs are video sources, the estimated maximum distances decreased significantly. For example, for a network of 4 UAVs, two of which transmit 4 Mbps video and the other ones are 2 Mbps video sources, the maximum range obtained was 83.4 km.

From the results obtained in the analysis of the real in-line scenario, it can be concluded that the network's increase is not linearly proportional to the number of nodes. The network's range is strongly influenced by the data rate. In addition, it is observed that, typically in networks where low data rate is observed (for example networks with a video source), the limiting factor is mostly the maximum LOS distance, since from a performance point of view of the SC or autonomy it is possible to reach higher distances. In the case where there are several video sources, the maximum LOS distance is not limiting. It should also be noted that the estimated ranges are within the desired values for the accomplishment of the missions in which it is intended to use the UAV system under study after the implementation of the pDDL2450 radios.

For the circular Scenario, a ships' column carrying out a mission that involves crossing the Atlantic Ocean, with a GCS in its centre, was considered. A similar analysis to the one performed for the L Scenario was done. It was verified that the higher the number of UAVs, the smaller the radius of the path described by them.

In the case where there is only one video source, the decreasing of the range (imposed by the SC) with the increase of the number of UAVs is minimal (<0.5 km with the addition of a UAV in the network). In the case where all the UAVs transmit video, the maximum distance imposed by the SC reduces significantly.

It should also be noted that the results obtained for Scenario C are adequate for detection of possible threats to offshore ships' columns.

Finally, it is possible to conclude that even though there are no problems from a coverage point of view, the system capacity is important in the network design, since it is the one that determines the maximum number of UAVs that can be used and the number of video sources. In addition, the network architecture is a determining factor to calculate the maximum possible distance to reach. It should be noted that, for example, in L Scenario the range increases with the increase of number of nodes in the network. In C Scenario the effect caused by the addition of UAVs is otherwise: the range decreases.

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