34th Congress of the International Council of the Aeronautical Sciences
ICAS Florence CONGRESS September 9-13 2024 ITALY

AI-ASSISTED DESIGN OF UAV DOCKING STATION NETWORK FOR DUAL USE PURPOSES

Arrigo Avi[1], Giuseppe Quaranta[2] & Alessandro Valentini[3]

[1,2]Dipartimento di Scienze e Tecnologie Aerospaziali, Politecnico di Milano, Milano, Italy
[3]Fondazione Bruno Kessler, Trento, Italy

Abstract

In this paper we propose a method to design a network of unmanned aerial vehicle docking station in order to perform dual-use activities. In particular, we aim to develop a method, based on Unified Planning library, part of the European AI On-Demand (AI4EU) platform, that could select best locations where docking station should be placed. Selection process will be based on target area in which operations will take place, in particular for search and rescue and reconnaissance.

Keywords: UAV, UAS, fleet network, AI, docking station, first responders, Trento

1. Introduction

Civil protection systems are complex and articulate [1]. There are lots of actors involved, but an important aspect joins all of them, they need to have a comprehensive situational awareness picture to deploy an effective emergency response. UAVs (Unmanned Aerial Vehicle) are an important tool; they are used often and the results prove their effectiveness. In particular they are useful for searching missing people, wildfires, notable accidents, surveying landslides and cliffs, and other important activities for prevention management. Armed forces make intensive use of drones for reconnaissance, target acquisition, etc. An improved schema, Figure 1, for deployment of unmanned aerial vehicle could be a fleet of UAVs, sheltered in docking stations. Docking stations could guarantee a safe takeoff and landing area, recharging, storage.

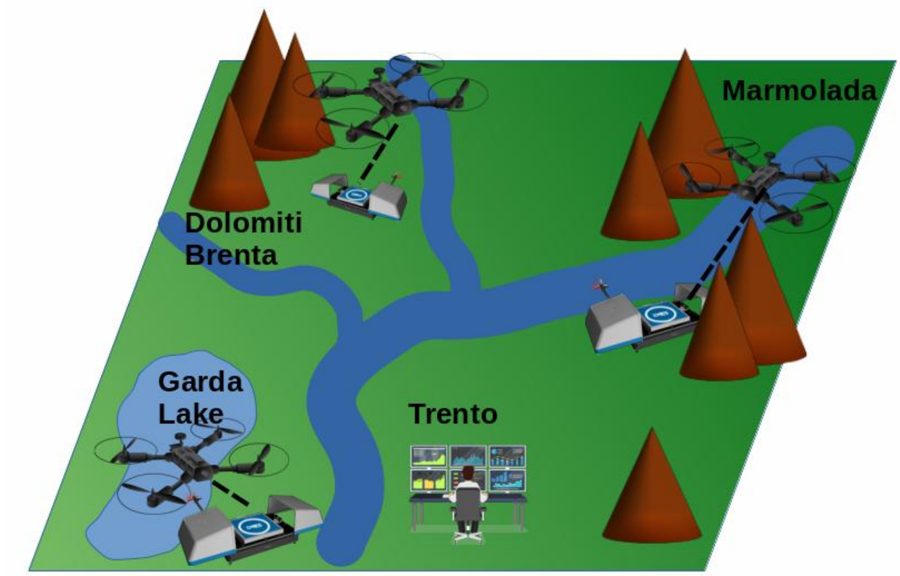

Figure 1 – Concept of operations for Provincia autonoma di Trento

Provincia autonoma di Trento (a region in the north of Italy, known for Dolomiti mountains) already has a first docking station that could be relocated inside the territory administrated. It recognizes that a UAV deployed with a docking station could be a game changer for civil protection activities.
Therefore, the final goal is to develop a fleet of high-performance UAVs, sheltered in docking stations, that could help the civil protection agencies to perform services in a better way: faster response, improved situational awareness, better reliability and availability, versatility.

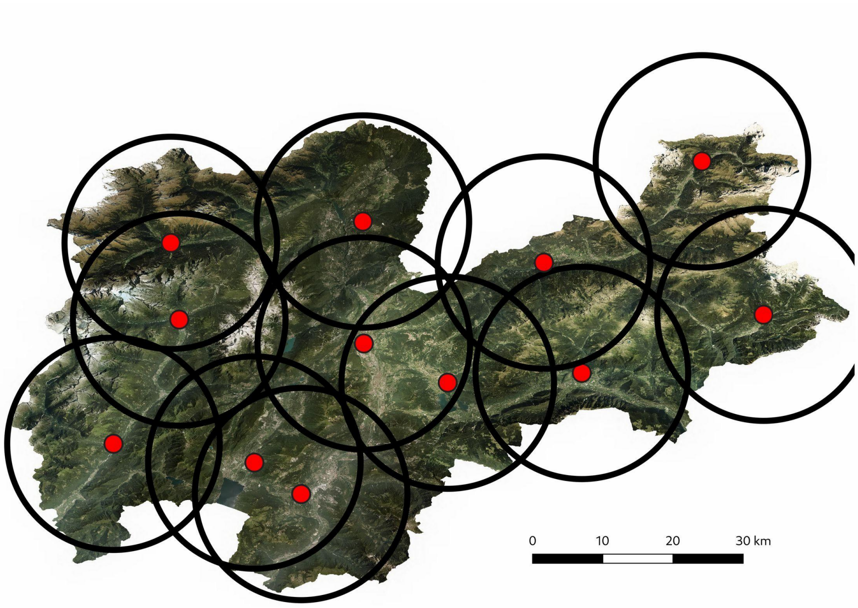

Figure 2 – First draft of docking station placement

An important aspect of designing a fleet of UAVs located inside docking stations is the best placement, a very first example could be seen in Figure 2. It depends on many factors: distance from the target area, suitable locations, data network coverage, and activity.
This paper illustrates the method that will be developed for the best placement of a docking station inside a defined area.

2. CONOPS

The main goal of this fleet of drones will be to have a fast and effective eye in the sky that could be deployed immediately when needs arise. SA (Situational Awareness) is considered crucial to making effective tactical decisions and actions at the scene [2]. First responders involved in a mission need to have the most accurate, complete and effective representation of the scene.
The concept of operations document highlights the paradigma that lie behind the project. It is a necessary step required by aviation competent authority in order to authorize operations. In this section will be explained how the planned operations will likely take place. For a better clarification the domain will be divided between air and ground.

2.1 Air section

UAS system will share the airspace with lots of other users like helicopters, gliders, planes, paragliders, etc. It is paramount to ensure separation between users. On this aspects lots of research and new regulations are developed and will not be investigated in this paper [3, 4].
The UAV tasked with a mission, takes off from the docking station. It flies following predefined routes previously computed by AI planning engines. When it reaches the appropriate area the aircraft could performed assigned tasks under manual or automatic control. After the completion of tasks UAV return to docking station, lands and recharge as needed. It is ready for a new mission.

2.2 Ground section

The ground section of the entire domain is divided into a competence area. Each competence area are managed by an UAS that could takeoff from the respective docking station. We choose to divide all the surface area in squares, each one spans about 900 km^2 (30 km each side). This choice follow an assessment that consider some important aspects.
The first aspect should be UAV. With so many type of aerial vehicle on the market it's difficult to choose a suitable machine. VTOL (Vertical Take-Off and Landing) aircraft seems promising, in terms of availability, reliability, size, and economical effort needed. VTOL could have a typical range of tens of kilometers and endurance up to 5 hours.
Another important aspect is the regulation that should allow operations. In particular, following previous experience of the deployment of a small docking station [1], we need to take into account the density of population nearest the docking station and in the operations area. Currently there are already some PDRA (PreDefined Risk Assessment) that could be used. PDRA are an already partially done risk assessment [5], by EASA. It should be improved and detailed for the submission of an operational authorization to the competent authority. The simplest one that could fit these operations is PDRA G-02. One of the main aspects highlighted by PDRA G-02 is the population overflown, the simplest and safest case will be when UAV overfly sparsely populated areas. So we tried to comply with this requirement in the selection of locations.
Other factors that are considered for an ideal placement of a docking station should be:

- power supply: charging batteries, maintain appropriate temperature inside are demanding tasks that require power supply, although there are lots of solution that could be deployed in remote areas, a permanent network is needed;
- high speed communication (fiber optic): reliable datalink is the most important aspect to be considered, a cabled interface that could act as a backup way is necessary;
- radio coverage: takeoff and landing could be performed under the radio coverage without any dedicated antenna mounted on docking station or the antenna necessary for the docking station could improve radio coverage significantly;
- unobstructed area: for takeoff and landing we need a safe area, enough to accomodate an emergency landing;
- corridors: permits fly over sparsely populated area;
- restricted area: necessary to avoid public areas.

In order to have a list of suitable places, a brief assessment was made. Of course, after the selection of the best docking place location, the competence area could be improved, but this aspect will be investigated in future works.

2.3 Operations

A brief flow chart on Figure 3 was developed to better clarify the operation sequences. Typically missions starts from a call to 112 (1^{st} level PSAP public-safety answering point), it selects the 2^{nd} level PSAP that should be involved and transfer call. The responding PSAP selects the best resources to allocate, including UAS. A dedicated UAS team will be dispatched, inside the main headquarter from a dedicated command control center, to deploy UAV for better situational awareness or other tasks as needed. With information about location, the best docking station will be selected and the planned route, previously computed, will be displayed. A request will be made to the U-space services that should release authorization (these steps will be heavily modified according to new regulation that will be developed). After authorization and pre-flight checklist, the UAV will execute mission. After reaching the target, depending on the tasks assigned, a persistence mode could be activated or recharge could be performed. At the end of the mission the UAV will fly to the docking station in order to recover and recharge.

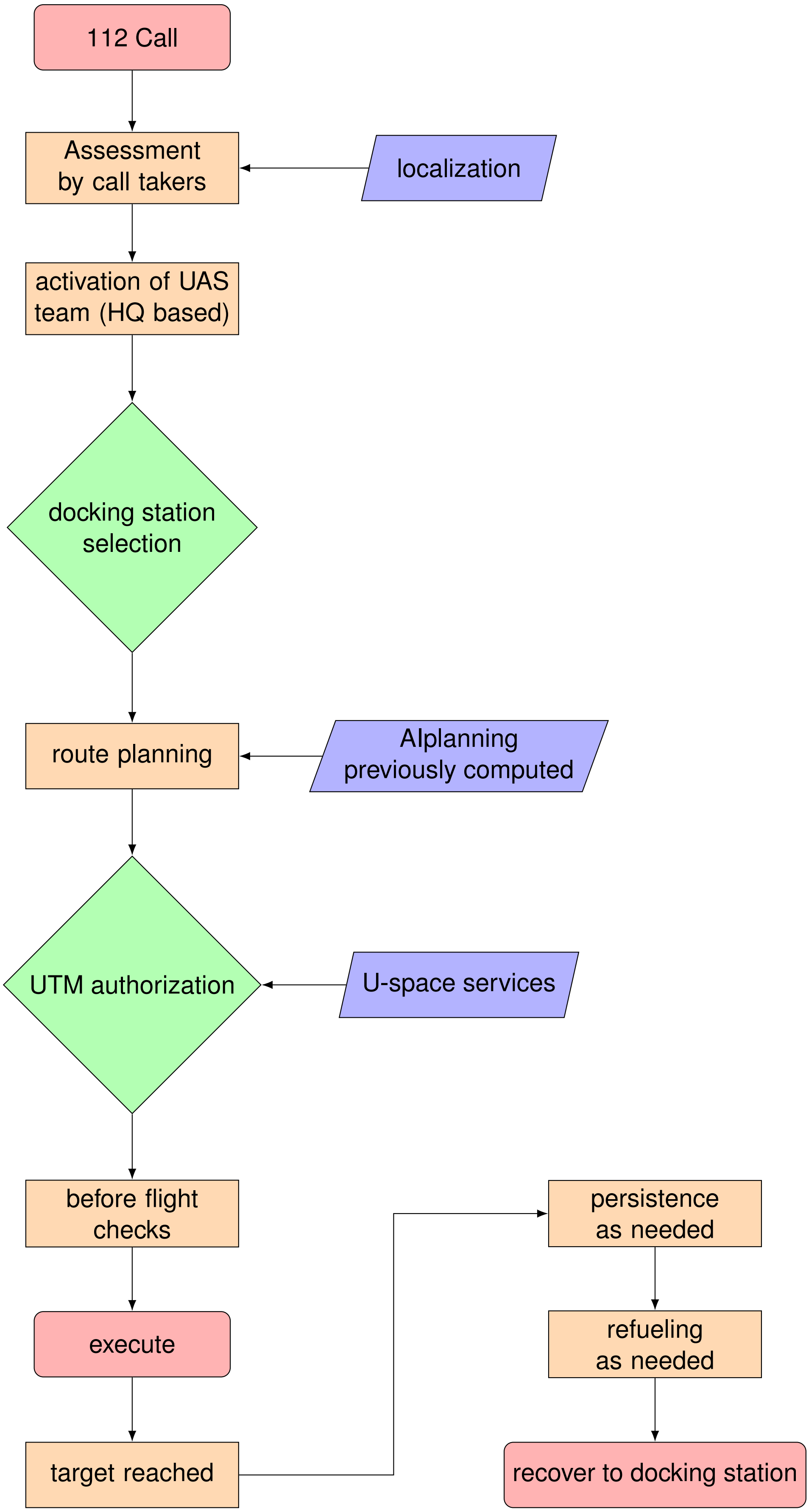

Figure 3 – operations flowchart

2.4 DUAL-USE

The main objective of this drone fleet is to improve situational awareness of events for firefighter departments. Specifically for forest fire, accident, searching missing people, landslide, etc.
UAVs are recently increased greatly their role from classical operations like survey and inspection to military specialized reconnaissance and combat. Due to the spreading of such systems, it is advisable to use it for many purposes. It could be used as a surveillance tool that could inspect a situation almost immediately. Or it could be employed as a tactical response to hazardous situations. Moreover a deployment near contested area could be imagined. Drones show actual effectiveness [6, 7, 8] in recent armed conflicts. Not only for surveillance missions, as typical in war area, but for resupply, medical evacuation [9], signal intelligence, etc. Drones could span through lots of specialized tasks in a war environment that poses huge risks to manned assets. The development of tools, like this designing tools, could improve the success of deployment.
On the same wavelength there are lots of efforts to integrate unmanned aerial and ground vehicles [10] that aims to deploy an all-unmanned solution. So an integrated planning system (ground and air based) would be beneficial too.

3. Methodology

Our method predicts the best point for the placement of a docking station and paths to reach every location inside the target area. We choose to compute paths, in the planning phase, for every location because it could be advantageous: we could determine the best docking station placement site and we have a set of paths already available for actual deployment. Of course during live operations, new elements could arise like obstacles (temporary cable), other traffics (manned assets or other aerial activity), weather (severe weather forecasting, etc.), but we have a solid plan database from which we could source.

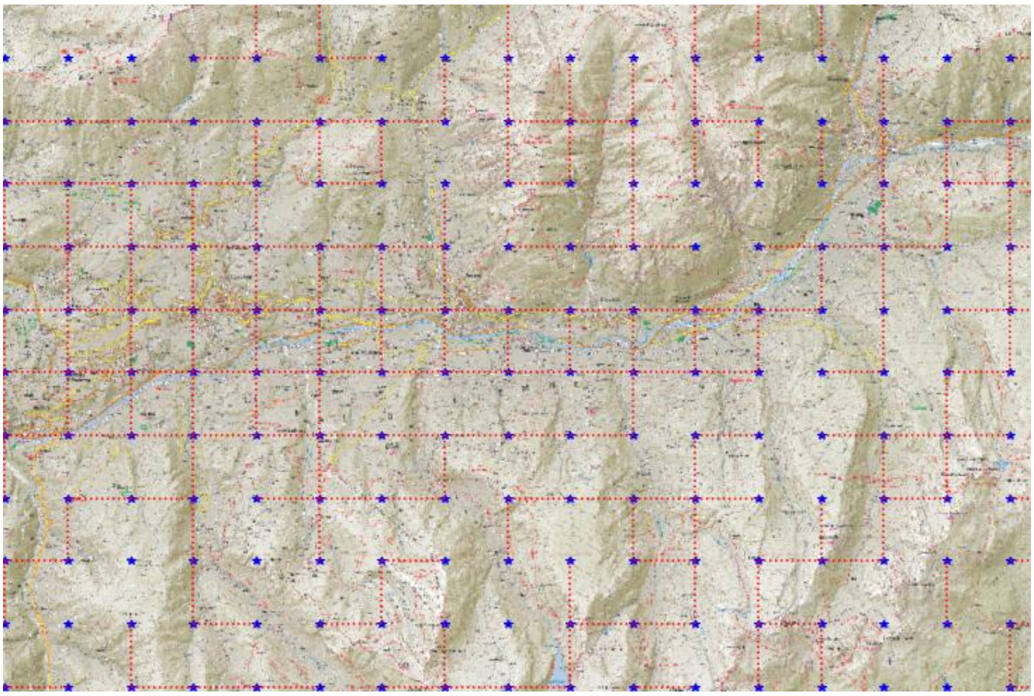

Figure 4 – Example of domain in Fiemme Valley

The entire air domain is divided into cells as in Figure 4. Each has a typical dimension of 1 km × 1 km and is simplified as a point (blue in Figure 4) that lies in the middle of the area. The altitude of this point is the maximum altitude of the corresponding area, in the same way as the MSA (Minimum Safe Altitude) depicted in aeronautical approach charts, plus 120 m (typical height limit of EASA regulation). Due to the performance limitation of the UAV that could be used (in our example the UAV has a typical cruise speed of 20 m s^{-1} and a climb rate of 4 m s^{-1}) we calculated that the maximum altitude difference between two adjacent points should be less than 200 m). Every point is connected to adjacent ones only if the altitude difference is within the performance of the UAV. In this way we have a set of interconnected locations that represent the allowable domain (red dotted line in Figure 4). UAV can fly only between connected locations.

3.1 DTM

The digital terrain model is a tool required for planning. In Trentino, more than 70 % of the surface lay over 1000 m above mean sea level. The local government periodically collects data for the development of a high resolution digital terrain model, typically less than 10 cm. For navigational purposes, the DTM was subsampled, reaching a resolution of 1 km. During the subsampling processing, resulting cells are computed taking into account the maximum value of altitude inside, in order to have a grainy area but with safe altitudes. After the processing the modified DTM will serve as a base for creating air domain with procedure as described in the previous paragraph.

3.2 Radio Coverage

Ensure reliable data connection between UAV and command and control systems are of prime importance. Although newest UAV could have satellite data connection, terrestrial radio network remain a fundamental assets to be developed. Trentino already has a well established radio network that could be improved in order to support UAV deployment. In particular there are more than 50 base station that could offer a wide radio coverage.
With the help of QGIS (a geographic information system software), we did a viewshed analysis. Viewshed analysis allows us to know if locations are visible from some observer points (base station). Typical datalinks used on unmanned assets use a range of frequencies between 1 GHz and 6 GHz, so we considered only the optical propagation of the signal. We considered every location at least 120 m above the terrain (typical flying heights of UAV) and observer points 20 m above the terrain. We obtained a radio coverage map, as shown in Figure 5, where red saturation represents how many radio base stations could be visible from the location and a dot blue represents a base station.

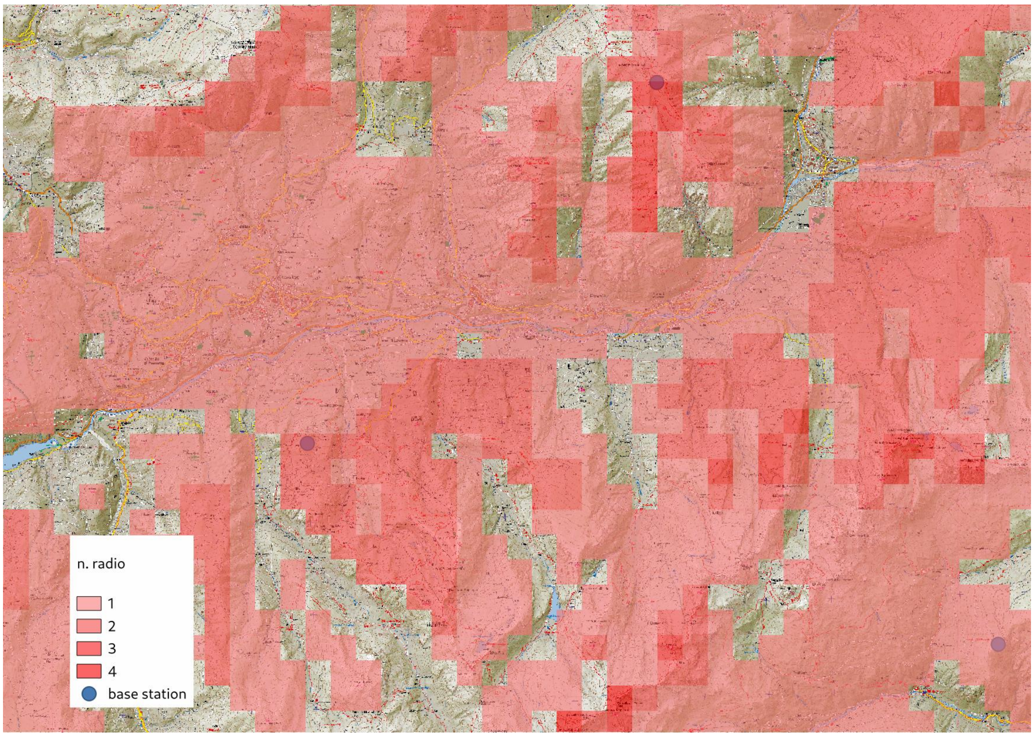

Figure 5 – Radio coverage map on remote area

3.3 Domain

The domain originates from the merging of DTM and radio coverage maps. Starting from the DTM map, the locations that are visible from at least one base station could be used, otherwise the locations are not usable. In this way we obtain a map in which there are just locations visible from at least one base station. Furthermore we know that some locations couldn't be reached due to no connection with other locations (too much difference in height or no line of sight to a base station). These locations are not reachable so it is necessary to improve the performance of the UAV (better climb rate or different platform) or the performance of the datalink (more base station).

3.4 Selection

One of the most energetically demanding task for an aircraft is to gain altitude. Our approach, in this first phase, for the selection of the best placement for a docking station was strictly related to the difference heights between locations that UAV fly during its flight. So the best docking station site will be the one that guarantee the minimum height gained during all the paths that start from the selected docking station to all locations that could be reached.

4. AI-assisted Design

4.1 European AI On-demand Platform (AI4EU)

European AI On-demand platform [11] is an European initiative that aims to develop an AI ecosystem that collects knowledge, algorithms, tools and resources available and makes it a comprehensive database for users interested in AI. AI4EU tries to unify artificial intelligence community in Europe, for a better availability to all users.

4.2 AIPlan4EU

Planning is one of the most important aspect in the design of UAVs network. AIPlan4EU [12] is a project that brings AI planning to the European AI On-Demand Platform. In particular, it collects the most advanced planning technology developed in Europe. As one of the most important outcome of this project, AIPlan4EU tries to make planning algorithm more accessible, facilitate the integration of planning state-of-the-art AI tools and standardize approach.
The python Unified Planning Library, born from AIPlan4EU project, is freely available on GitHub [13], it permits to simply define planning problems in terms of domain, fluents (variables), constants, actions. After the definition, the problem will be solved through some internal planning engines (Aries [14], Tamer [15], LPG [16], fast-downward [17], etc.). Planning engines could solve classical, numerical, temporal problems taking into account metrics.

4.3 Problem

The planning of a path inside a domain is modeled as an action-based numeric planning problem. In the following we made a brief presentation of the code used, some extract are represented in Listing 1.
Fluents are variables of a planning problem, in our case we have:

`drone_at` represent the location where UAV is;

`connected` represent the connection between two locations;

`altitude_difference` represent the height difference between two locations;

`total_heights` represent the sum of all differences;

Each fluents can change over time. We define the action that we have in our problem. In this case we have only `move` as an action. We could define preconditions or effects of this action. In our case we have, in particular, the effect that every move increase the `total_heights` by `altitude_difference`. When we have fluents and actions we could create the problem itself. Before solving the problem we need to set the initial value of fluents: the starting position in `drone_at`(a possible docking station position), all connections in `connected`. We could add our condition to met (minimize `total_heights` value) and the goal (a location of the grid).
The library could select automatically the best solver based on the problem depicted. The best available planning engine, in the library, for this type of problem is ENHSP [18]. In few seconds we

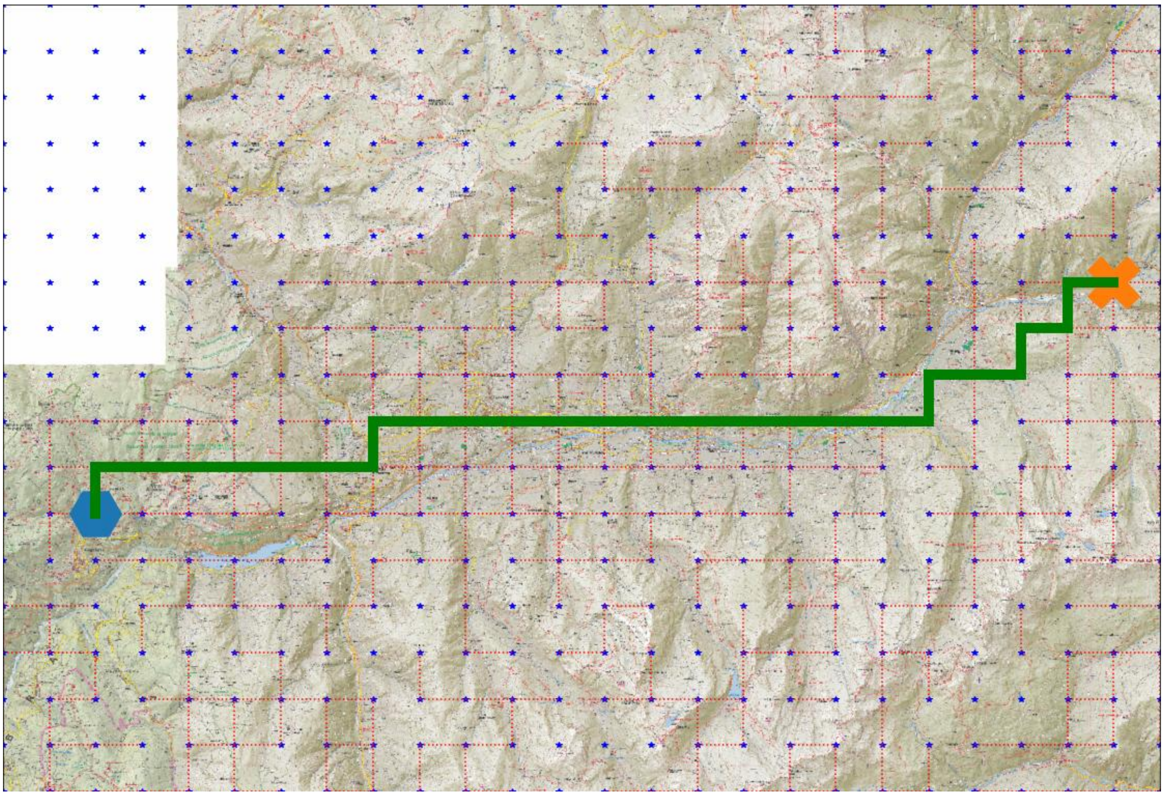

Figure 6 – Example of a single path generated

obtain a solution, Figure 6, for each location of the grid. The blue hexagon is the docking station location, orange cross is the target, green line represents the path.
The selection of the best location is made through the sum of `total_heights` of every solution (an example of some paths could be seen in Figure 7) computed from the same location, compared with other locations. In this way we obtain the docking station placement that could guarantee the minimum effort in terms of gaining height for an UAV.

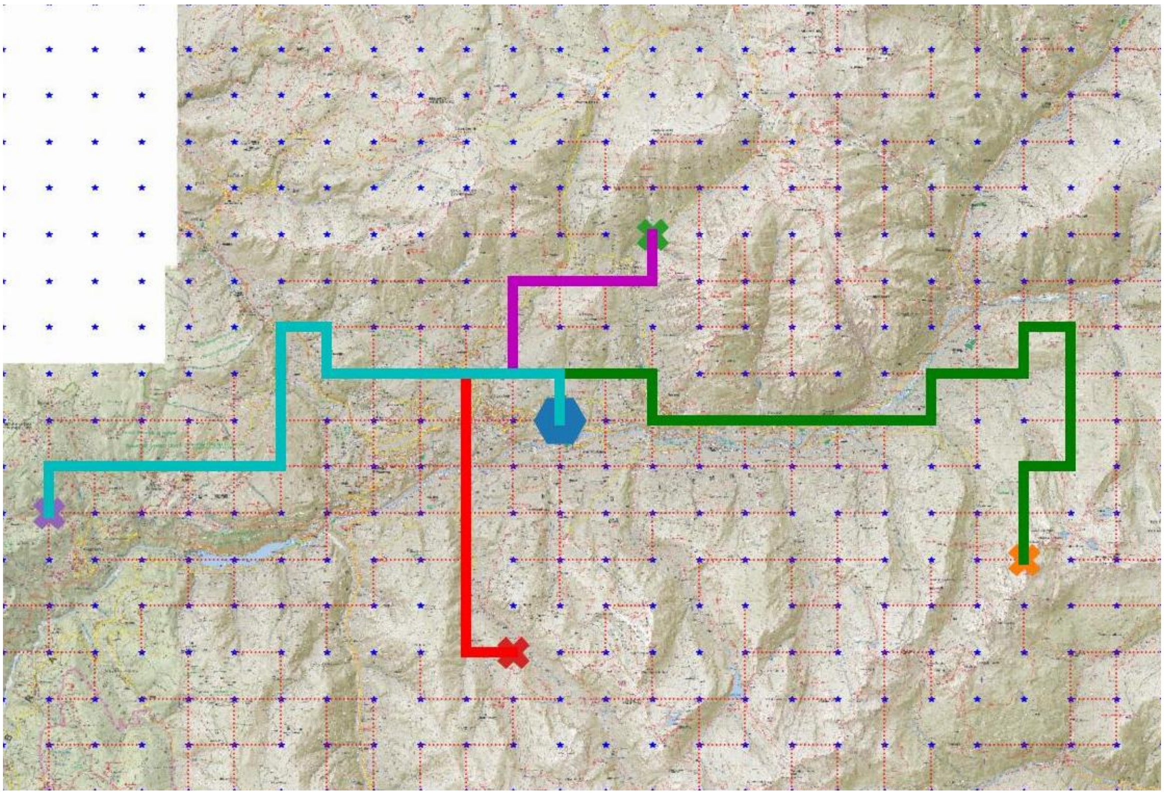

Figure 7 – Some path from the best candidate site

Listing 1: Extraxt from the python code

```python
# fluents
drone_at = unified_planning.model.Fluent(...)
connected = unified_planning.model.Fluent(...)
altitude_difference = unified_planning.model.Fluent(...)
total_heights = unified_planning.model.Fluent(...)

# action
move = unified_planning.model.InstantaneousAction(...)
l_from = move.parameter(...)
l_to = move.parameter(...)
move.add_precondition(connected(l_from, l_to))
move.add_precondition(drone_at(l_from))
move.add_effect(drone_at(l_from), False)
move.add_effect(drone_at(l_to), True)
move.add_increase_effect(total_heights, altitude_difference(l_from, l_to))
[...]
# problem
problem = unified_planning.model.Problem('drone')
problem.add_fluent(drone_at, default_initial_value=False)
problem.add_fluent(connected, default_initial_value=False)
problem.add_fluent(altitude_difference, default_initial_value=0)
problem.add_fluent(total_heights, default_initial_value=0)
problem.add_action(move)
problem.add_quality_metric(MinimizeExpressionOnFinalState(total_heights))
[...]
# initial value
problem.set_initial_value(connected(locations[id], locations[id+1]), True)
problem.set_initial_value(altitude_difference(...))
problem.set_initial_value(drone_at(locations[start_x+start_y*cols]), True)

# goal
problem.add_goal(drone_at(locations[goal_x+goal_y*cols]))

# solve
with OneshotPlanner(name='enhsp') as planner:
    result = planner.solve(problem)
```

5. Expected outcomes

This paper illustrates just a single step of a larger project that aims to build a network of UAV operated from docking stations inside Provincia Autonoma di Trento . We expect to create a method to design network of UAVs that could be used for deployment in area typically less than 10 000 km^2.
This first step highlights multiple new objective for a better design of a UAV network.
We need to refine the parameters that we use for the selection process. We used just the relative difference in height but it isn't enough, we should investigate with multiple parameter.
We have a very high resolution digital terrain model, we subsampled to 1 km x 1 km. We'll investigate in the improvement of the efficiency of this planning engine in order to use a more detailed DTM, that led to better, more realistic (we will have less un-connected locations) and reliable paths.
We use some simple data from UAV manufacturer, an interesting enhancement could be the integration of a model of the aerial vehicle that aim to evaluate the feasibility of the path.

6. Aknowledgements

The authors are grateful for the AIPlan4EU project support, which was funded by the European Union's Horizon 2020 research and innovation programme under GA 101016442.

7. Contact Author Email Address

arrigo.avi@polimi.it

8. Copyright Statement

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