Structuring Air Logistics Networks in the Urban Space

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Bruno Lamiscarre worked first at Onera in several locations Chatillon, Meudon and Toulouse in France. He has acquired over 16 years in the Physics Scientific Branch a large experience in the domain of Optical Sensors and Signal processing. Since 1997, he has been involved in the field of Airport related research within the frame of the project called « Airport of the future » as the head of this project. He was involved in EU projects in the field of Air Transport System (ATS) covering, Drones, Airports, Automation, Fast time simulation, Security. Since 2007, he was the program manager of IESTA platform development: IESTA is a fast time simulation of the ATS with particular focus on environmental issues and future ATS concepts.

He joined ENAC (Ecole Nationale d'Aviation Civile), the French civil aviation university, in 2010 and until mid 2014, he was the Director for Research, in charge of the development of ENAC research on academics grounds but also towards applications like Unmanned Aircraft System (UAS), Air Traffic Management (ATM) and Airports, Human Machine Interface (HMI) in Aviation, Sustainable Air Transport, Safety.

Since then and until march 2017, he was back at ONERA to take the responsibility of the Systems Control and Flight Dynamics department. The department is focused on control and piloting, monitoring and decision, robotics systems, HMI and Human factors, and System design for aerospace vehicles and systems.

In the framework of new ONERA organisation in 2017, he took the position of Program Director of the Air Transport System Directorate. More specifically, he was coordinating the whole ONERA research activities in the domains of ATM (including UAS Traffic Management - UTM), Airport and Avionics Systems.

Since he left ONERA in December 2018, he joined NeoMetSys as the Scientific Director and the Asia Pacific Director.

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NeoMetSys knowledge and skills in Aviation

- Collaborative Decision Making (CDM) and Airport CDM (A-CDM)
- Traffic Flow Management (ATFCM – Air Traffic Flow and Capacity Management), Dynamic Airspace Configuration (DAC)
- Dynamic Capacity Balancing (DCB)
- Trajectories Optimization (Airstreams)
- Commercial Aircraft and Drones Traffic Simulation
- Urban Air Mobility (UAM): Airspace Design, Trajectories optimization, Traffic complexity, Detect & Avoid, Societal Acceptance, Drone Regulation

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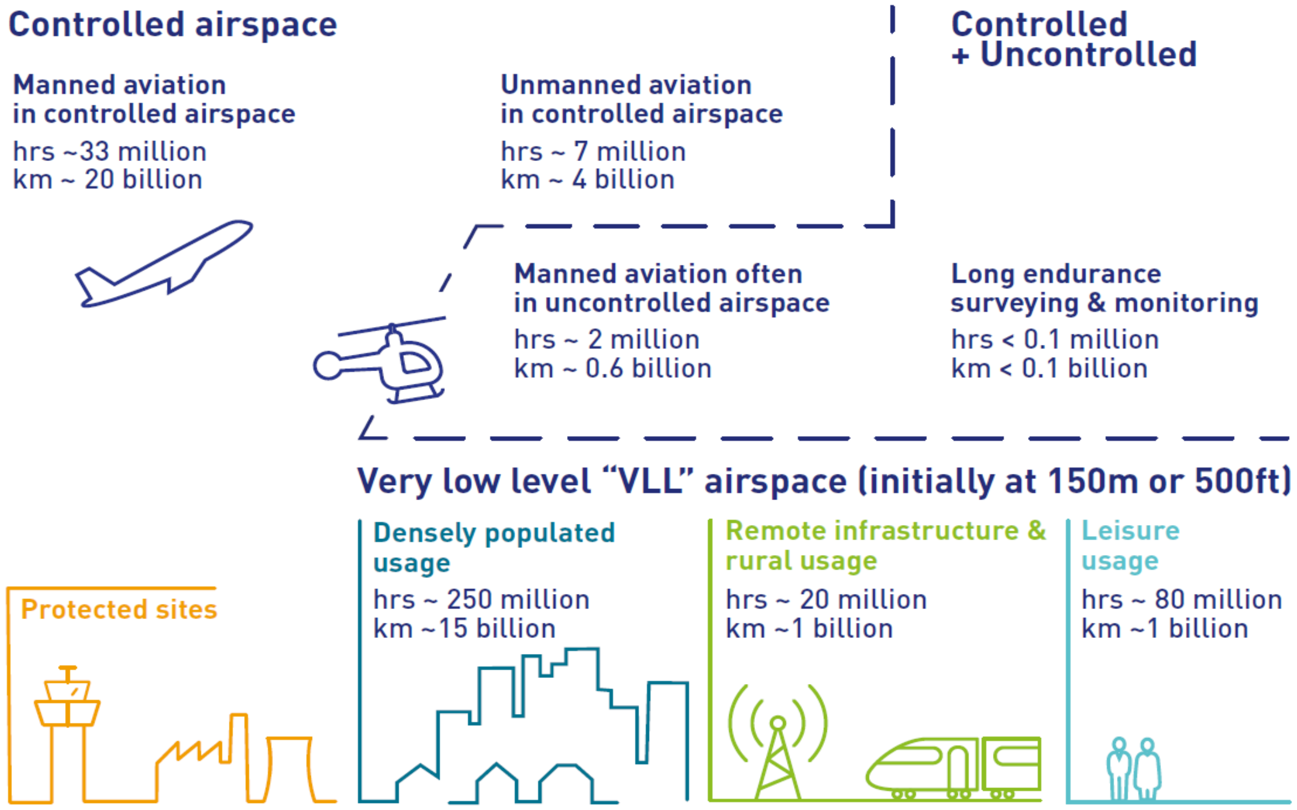
1- Motivation

- Unexplored problem of designing a network in a urban airspace so that Unmanned Air Vehicle (UAV) based logistics can be performed efficiently
- A structure for the lower layers of the urban airspace is proposed
- Then an optimal network design problem is formulated
- And a heuristic solution approach is developed
- Validation through a small scale urban network model

2- Introduction (1/2)

High potential of development of Urban Air Mobility (UAM), specially for Aerial Logistics, see SESAR ATM Masterplan 2020:



2- Introduction (2/2)

Why?

- Fast technological development (electrical engines, navigation & guidance systems and communication devices)
- Increased availability of commercial UAVs at low cost and a wide range of payload (1.5 Kg to 350 Kg) and mission endurance (30 minutes to several hours)
- Regulation & services are in progress worldwide (BVLOS, CE marking, UTM in USA, U-space in Europe)

What?

- High traffic needs organization to reach capacity & safety goals
- Hence, designing an urban airspace and optimize it is compulsory

3- Adopted Assumptions and Objectives

- Medium to low flying speed: less than 50 m/s (in general rotorcraft)
- Adoption of a common speed V_L inside the movement slice
- High maneuverability allowing to perform tight turns and vertical flight level changes
- Full navigation coverage of urban area through onboard integration of vision, ground references and GPS segments
- Autonomy in guidance along planned trajectories with centimeter accuracy
- Autonomous collision avoidance capability (Detect & Avoid)
- Small/medium payload capability
- On board loading/offloading interfaces
- Soft landing capability in case of failure or damage

4- Demand Characteristics

- Point-to-point deliveries: between 2 entities, relatively low volume
- Hub and Spoke system of deliveries: collective urban services, high volumes from hubs (big stores for instance) to particular; ground bulk transportation to feed the hubs
- Stochastic nature of the demand
- Demand is spatially and temporally distributed

=> For planning purposes, it will be considered origin-destination matrices representative of the demand over a given period of time, typically one hour

5- Main objectives and constraints for the urban air logistic traffic network (L-network)

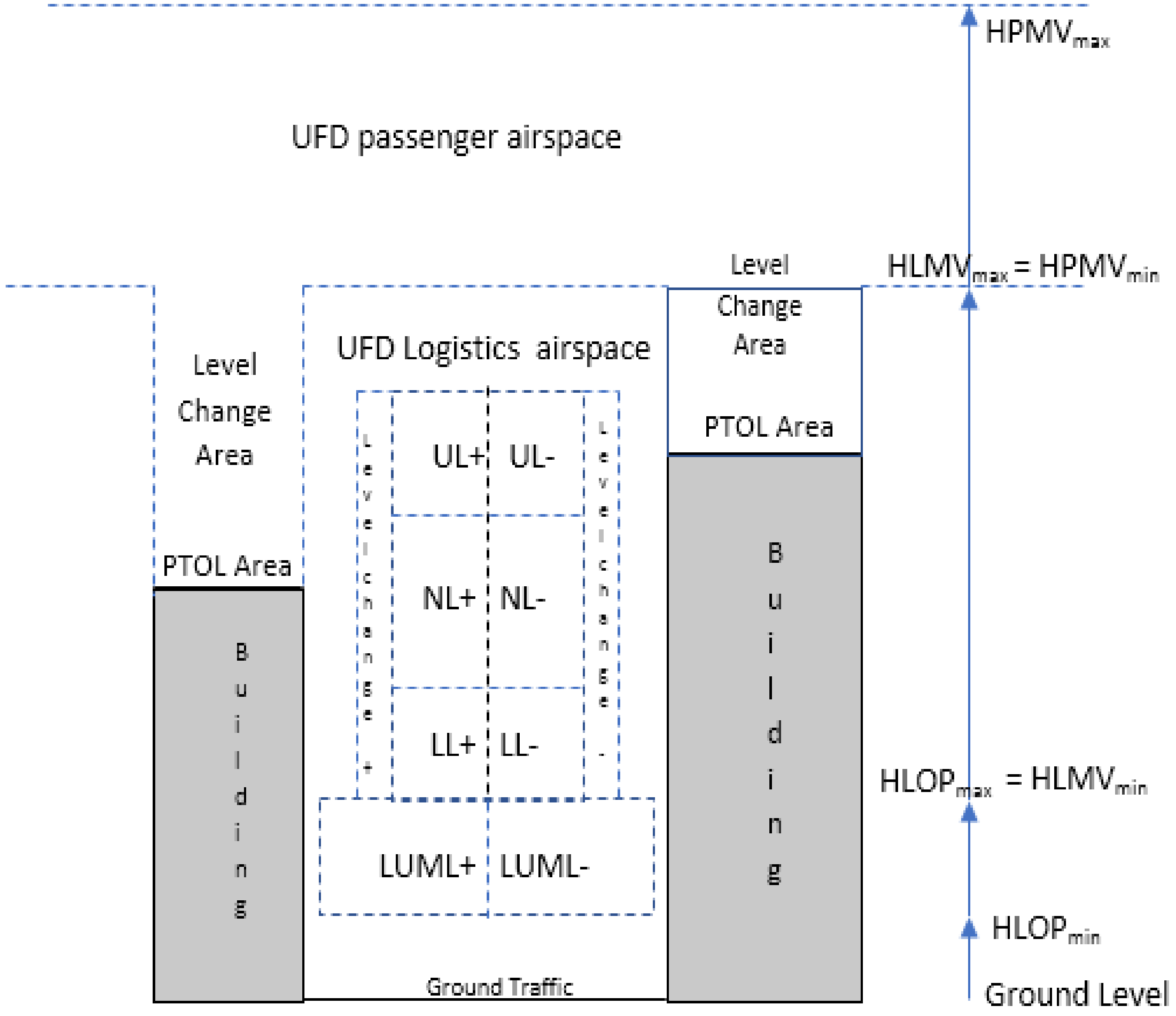
Constraints:

- The L-network should provide reachability for any origin-destination pair associated with a demand: implies connectivity of the graph underlying the traffic network
- The L-network is a capacitated network where each link capacity is supposed to be able to cope with its planned traffic

Main Objectives:

- The L-network should minimize investment: assess through the total weighted length (weight is related to the installed capacity)
- The L-network should also propose for each demand a minimum "length" connection as a path of the underlying graph
- Safety and Environmental impact should also be considered

6- Structuring the Urban Airspace



UFD: Unmanned Flying Device, Logistics traffic and Taxi traffic are segregated
PTOL: Passengers UFD Take-off and Landing
NL+/NL-: Constant altitude Logistics UFD in both directions along the streets
UL+/UL-: Upper crossing manoeuvers areas
LL+/LL-: Lower crossing manoeuvers areas
LUML+/LUML-: traffic toward delivery or maintenance
HPMVmax: maximum altitude for passengers traffic
HPMVmin: minimum altitude for passengers traffic
HLMVmax: maximum altitude for Logistic traffic
HLMVmin: minimum altitude for Logistic traffic
HLOPmax: maximum altitude for Logistic Docking or Dedocking
HLOPmin: minimum altitude for Logistic Docking or Dedocking

7. The Optimal Design Problem

Notations:

- P_{ij} : the set of elementary paths linking the origin i and the destination j in the air logistic network of graph $[X_2, U_2]$.

- U_{ij}^{k} : the set of edges composing the k^{th} path between i and j.

- CP_{ij}^{k} : the cost of the k^{th} path between i and j in X_{OD}:

$$CP_{ij}^{k} = \sum_{(h,l)\in U_{ij}^{k}} C_{hl}$$

- $[a_{ij}^{khl}]$: the incidence matrix between the k^{th} path between pair (i, j) and air link (h,l): $a_{ij}^{khl} = 1$ if (h,l) belongs to the k^{th} path between i and j, otherwise, a_{ij}^{khl}=0.

The Optimal Design Problem

Minimize total cost: $\sum_{i \in X_{OD}} \sum_{j \in X_{OD, j \neq i}} \sum_{k \in P_{ij}} CP_{ij}^{k} \cdot x_{ij}^{k}$

under the constraints:

$$\sum_{i \in X_{OD}} \sum_{j \in X_{OD, j \neq i}} a_{ij}^{khl} \cdot MT_{ij} \cdot x_{ij}^{k} \leq CT_{h,l} \quad (h, l) \in U_1, h \neq l \qquad \text{(a)}$$

$$\sum_{k \in P_{ij}} x_{ij}^{k} = 1 \quad i, j \in X_{OD}, i \neq j \qquad \text{(b)}$$

$$x_{ij}^{k} \in \{0, 1\} \quad k \in P_{ij}, \quad i, j \in X_{OD}, i \neq j \qquad \text{(c)}$$

Here constraints (a) are capacity constraints for all the edges of the air logistic network, constraint (b) assumes that all the demands between the pairs *i, j* of X_{OD} use only one path and constraints (c) recall the binary nature of the considered decision variables.

8- Heuristic Solution Method

Steps of the proposed Heuristic Solution Method:

- a) Compute the minimum cost paths between the pairs (*i, j*) of X_{OD} .

- b) Rank by decreasing logistics demand levels the pairs (*i, j*) of X_{OD}.

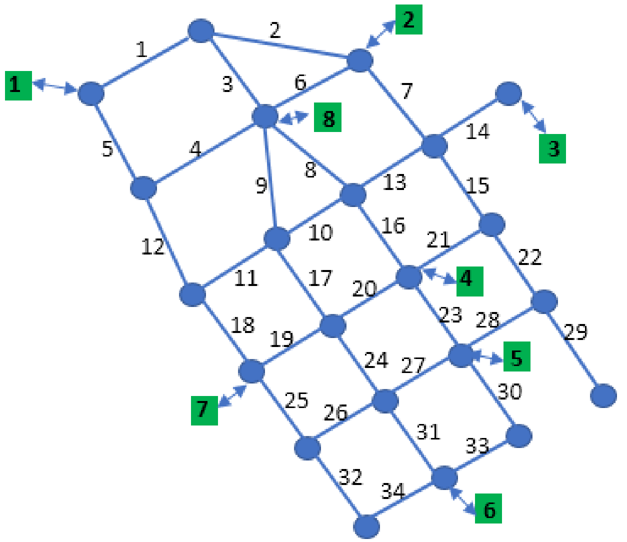
- c) Assign according to this ranking demand MT_{ij} to the minimum cost path between *i* and *j* taking into account the minimum capacity of the edges of the paths.

- d) Compute for each edge in the air logistics network its resulting flow F_{kl}, $(k, l) \in U_1$ by adding up the flows in the paths which contain that edge.

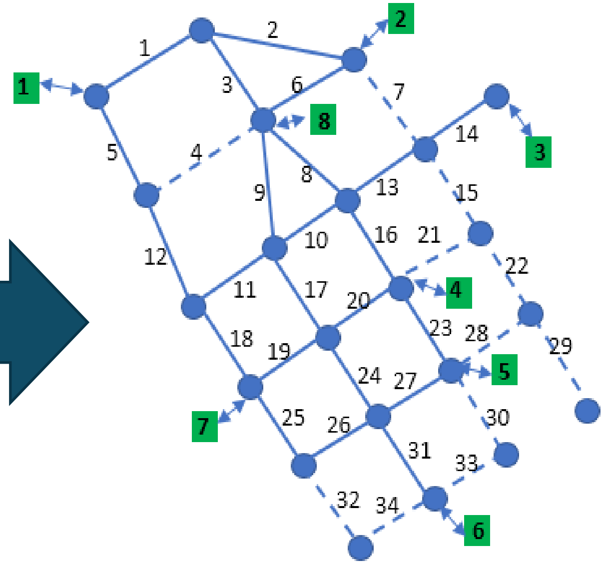
- e) A threshold F_{min} can be considered so that edges such as $F_{kl} < F_{min}$ are deleted from the air logistic network unless they insure connectivity.

Heuristic Solution Method

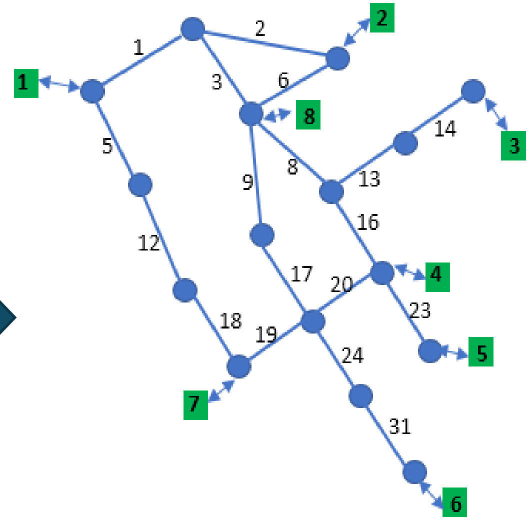
Example of application of the proposed heuristic:



Example of a network of streets and supply and delivery nodes



First reduction of the network taking into account the demand which makes it possible to eliminate the unused segments



Elimination of segments below a minimum flow threshold, while containing the increase in travel time to less than 30% for only 5% of traffic

9- Conclusion

- Design of a network of urban airways allowing mobility and ensuring accessibility to operate traffic flows of UAVs devoted to general logistics over an urban area.
- Proposed method using classical concepts and algorithms of graph theory and since the exact optimization problem is in practice intractable for real size problems; a heuristic solution approach that is more computer friendly is developed.
- Proposed approach is preliminary but a systematic approach such as the one described in this communication leads to a feasible modeling and optimization
- A validation by simulation at the scale of a whole city would be useful to complete this feasibility study.

Thank you

Questions?

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