Distributed UAV Traffic Management

How IoT and UAVs Shape the Future

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PCOG Team Meeting – 14th Dec 2020

General Information

- **Background**
  - Engineering – Mechatronics and Aerospace
  - PhD Candidate – Joined PCOG in October 2017
  - IoT and UAVs – Joint Program SnT-ILNAS
- **Research and Standardisation**
  - Scope of PhD – next generation UAV Traffic Management system (UTM $^{2.0}$)
  - Standardisation – national delegate / HoD at NMC and ISO
  - Status – Finalising and writing thesis
- **Closing Remarks**
  - Standardisation and innovation
  - The potential, the challenge and the opportunity

IoT in Aerospace Sector

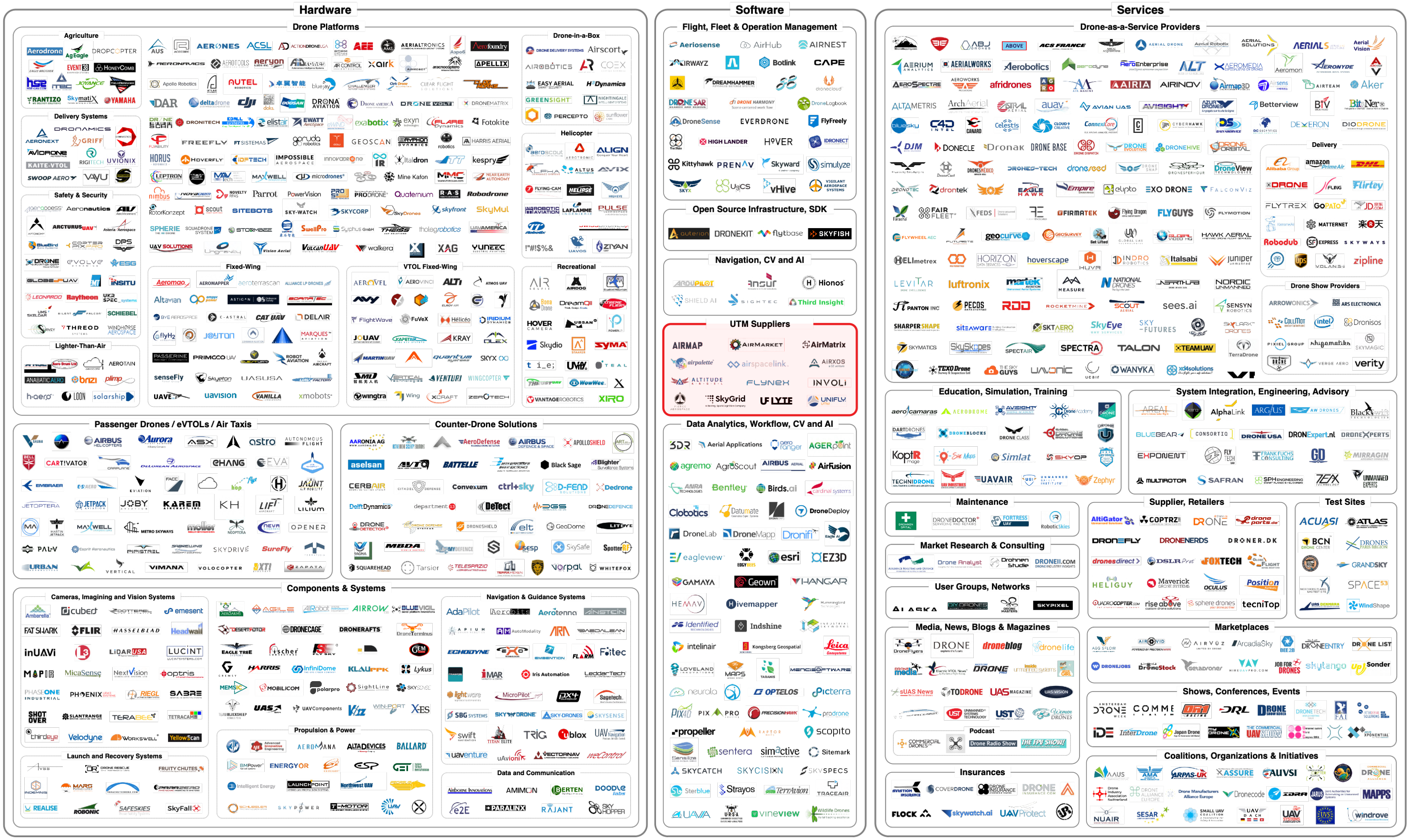
Transformation of Aerospace

- Introducing new concepts and space missions (Starlink, OneWeb, etc.)
- Enhancing flight sensory systems
- Reducing grounding time
- Improving management and maintenance

One subsector that is rapidly expanding is commercial Unmanned Aerial Vehicles (UAVs)

- The global commercial UAV market set to reach $46.4B in 2025 from $17.8B in 2019
- Compound Annual Growth Rate (CAGR) of 20.5%
- The number of UAVs will grow from 12.2 million in 2019 to over 18.1 million in 2025
- Potential applications ranging from monitoring to logistics and eHealth
- Scalable and resilient UAV Traffic Management (UTM)

https://www.cbi.eu/market-information/outsourcing-itobpo/internet-things/ https://www.iso.org/news/ref2419.html


Hardware
Drone Platforms
Agriculture
Delivery Systems
Safety & Security
Lighter-Than-Air
Fixed-Wing
VTOL Fixed-Wing
Drone-in-a-Box
Helicopter
Recreational
Passenger Drones / eVTOLs / Air Taxis
Counter-Drone Solutions
Components & Systems
Cameras, Imaging and Vision Systems
Launch and Recovery Systems
Propulsion & Power
Navigation & Guidance Systems
Data and Communication
Software
Flight, Fleet & Operation Management
Open Source Infrastructure, SDK
Navigation, CV and AI
UTM Suppliers
Data Analytics, Workflow, CV and AI
Services
Drone-as-a-Service Providers
Delivery
Drone Show Providers
Education, Simulation, Training
System Integration, Engineering, Advisory
Maintenance
Supplier, Retailers
Test Sites
Market Research & Consulting
User Groups, Networks
Media, News, Blogs & Magazines
Podcast
Marketplaces
Shows, Conferences, Events
Insurances
Coalitions, Organizations & Initiatives

UAV Traffic Management (UTM)

Motivation

Authorities and society seek solutions to overview all UAVs, users and traffic, especially in cities
→ UTM

Key Challenges

- Centralised systems
- Poor scalability and resilience
- Lack of regulations and technical standardisation

UAV Traffic Management (UTM)

Research Goal

A UTM with distributed decision making allows for better scalability and resilience.

Research Questions

Investigate the possibility of developing a fully distributed UTM that is capable of intelligently handling highly dynamic and challenging traffic conditions.

i. How to model the UAV traffic in the class G airspace?

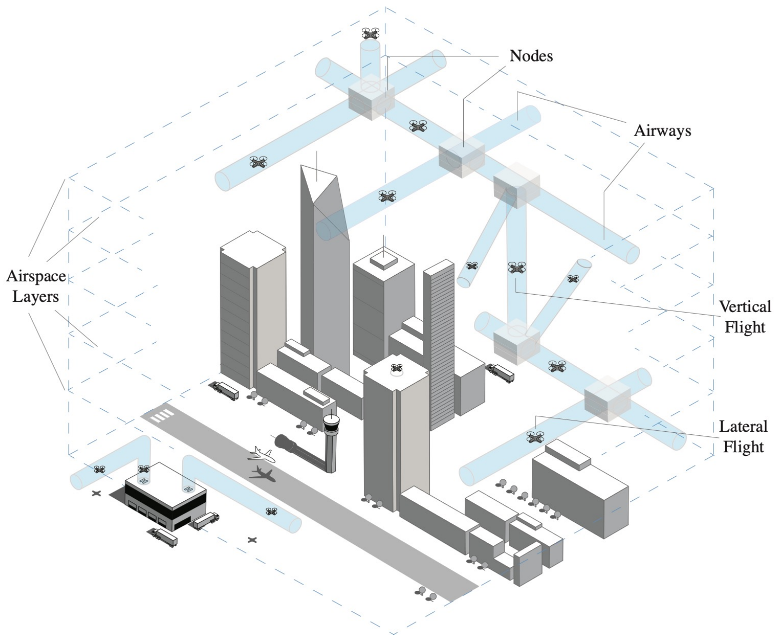
ii. How to define optimisation model(s) encompassing problem specific constraints (3D mobility) and objectives (time, energy, connectivity)?

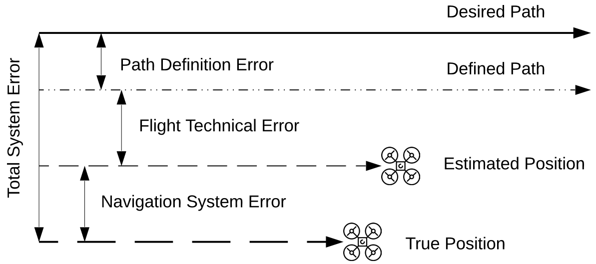
iii. How to design distributed UAV traffic behaviours that benefit the global traffic system?

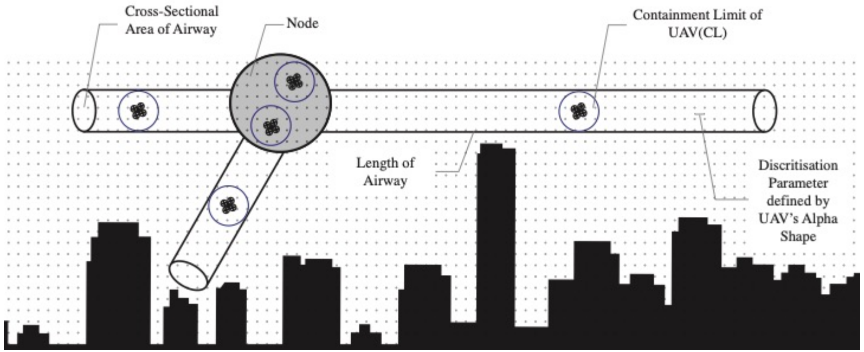
iv. What role standardisation plays in UTM development and how research and standards can align to address obstructing challenges?

Multilayer Low-Altitude Airspace Model

Low altitude airspace







S. Labib, N.; Danoy, G.; Musial, J.; R. Brust, M.; Bouvry, P. A Multilayer Low-Altitude Airspace Model for UAV Traffic Management. In Proceedings of the 9th ACM Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications DIVANet'19. ACM, 2019.

Multilayer Low-Altitude Airspace Model

Multilayer Multi-weighted Network Model

$$M_{ClassG} = (G_M, N, W_E)$$

The airspace contains a non-empty set of layers N, each layer being represented as a graph of nodes and airways $G_M = (V_M, A_M)$. Nodes can belong to one or more layers.

$$V_M = \bigcup_{\alpha=1}^{|N|} V^{\alpha}; \alpha \in N$$

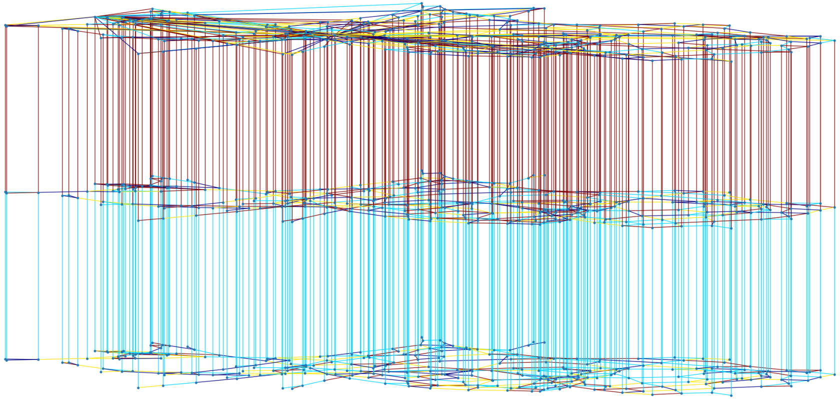
Each edge, i.e. airway, is assigned three different weights defining travel time, energy cost and traffic capacity respectively: $a_M = (u, v, \alpha, t, e, c)$ with $u, v \in V_M$, $\alpha \in N$ and $t, e, c \in W_E$, a non-empty set of weights at event step, E.

The set of edges is composed of intra-layer edges, i.e., airways within one layer (A^{α}), and inter-layer edges, i.e., airways connecting layers ($A^{\alpha,\beta}$), with $\alpha, \beta \in$ N.

$$A_M = \left(\bigcup_{\alpha=1}^{|N|} A^{\alpha}\right) \bigcup \left(\bigcup_{\alpha,\beta=1,\alpha\neq\beta}^{|N|} A^{\alpha,\beta}\right),$$

with $A^{\alpha} \subseteq V^{\alpha} \times V^{\alpha}$, and V^{α} a finite, non-empty set of nodes on layer α, and $A^{\alpha,\beta} \subseteq V^{\alpha} \times V^{\beta}$; with $\alpha, \beta \in N$, $\alpha \neq \beta$ and V^{β} a finite, non-empty set of nodes on layer β.

Belval Campus Map



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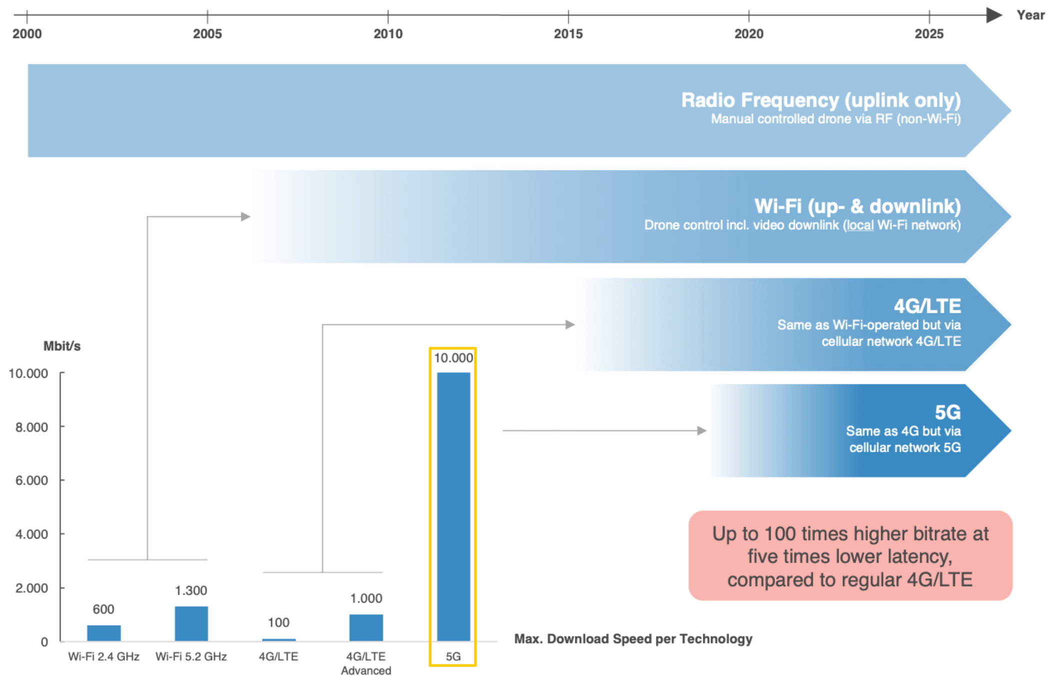
UAV Connectivity

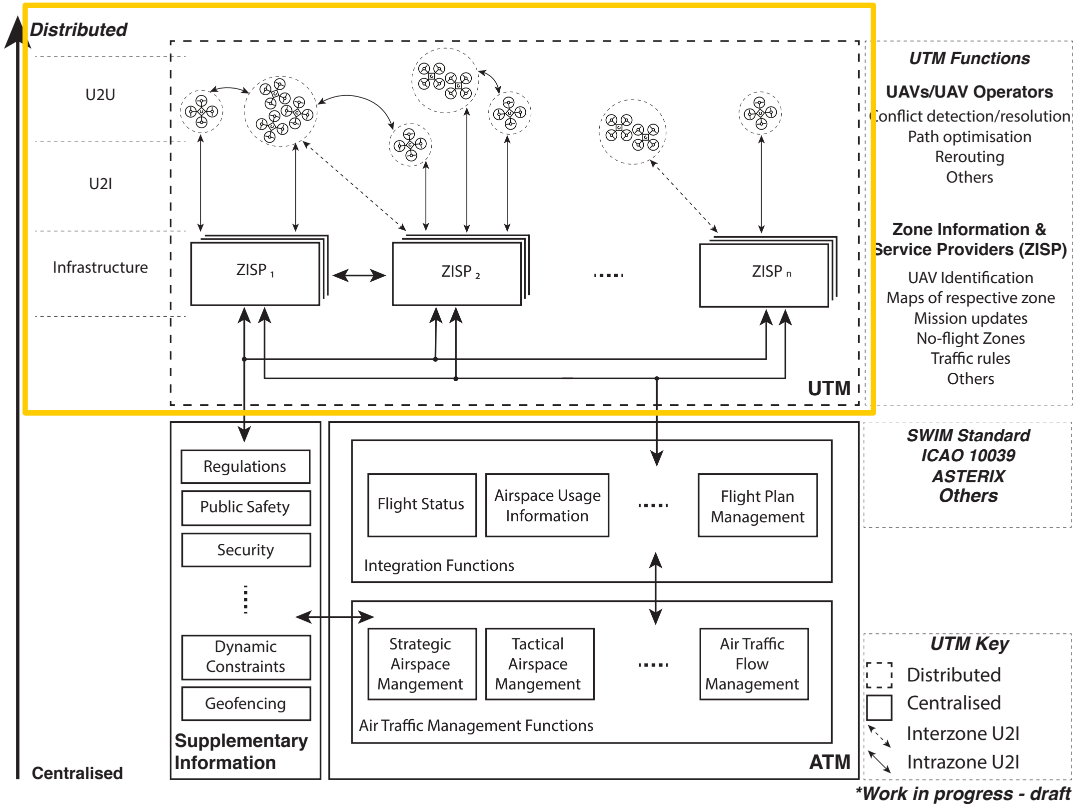
Evolution of UAV Connectivity and Role of 5G – U2X



UAV Connectivity

UTM information flow

Tactical Level

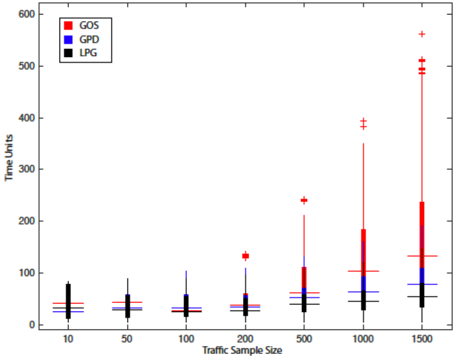


UAV Traffic Optimisation

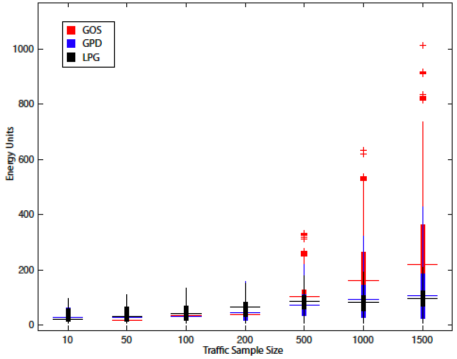
- **Stage one – validation stage**

We proposed and evaluated three heuristics:

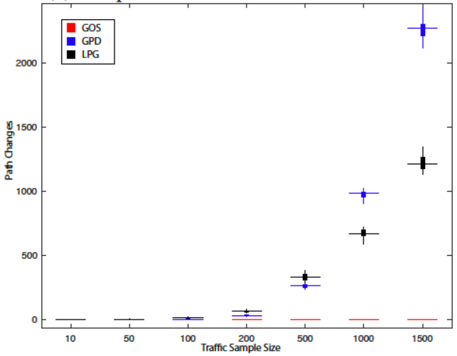
- Static deterministic heuristic
  Global Offline Static – UTM (GOS)
- Probabilistic heuristic with global knowledge of network
  Global Probabilistic Dynamic – UTM (GPD)
- Probabilistic heuristic with local 1 hop knowledge of traffic conditions
  Local Pheromone Guided – UTM (LPG)



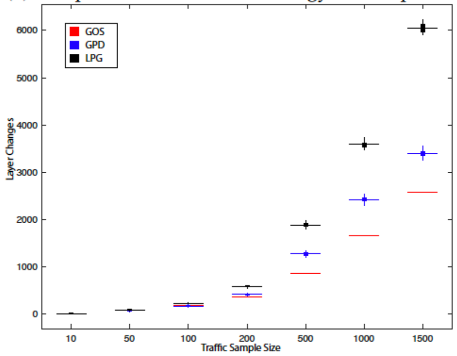
(a) Comparison of total UAVs' travel time.



(b) Comparison of total UAVs' energy consumption.



(c) Comparison of total UAVs' path changes.



(d) Comparison of total UAVs' layer changes.

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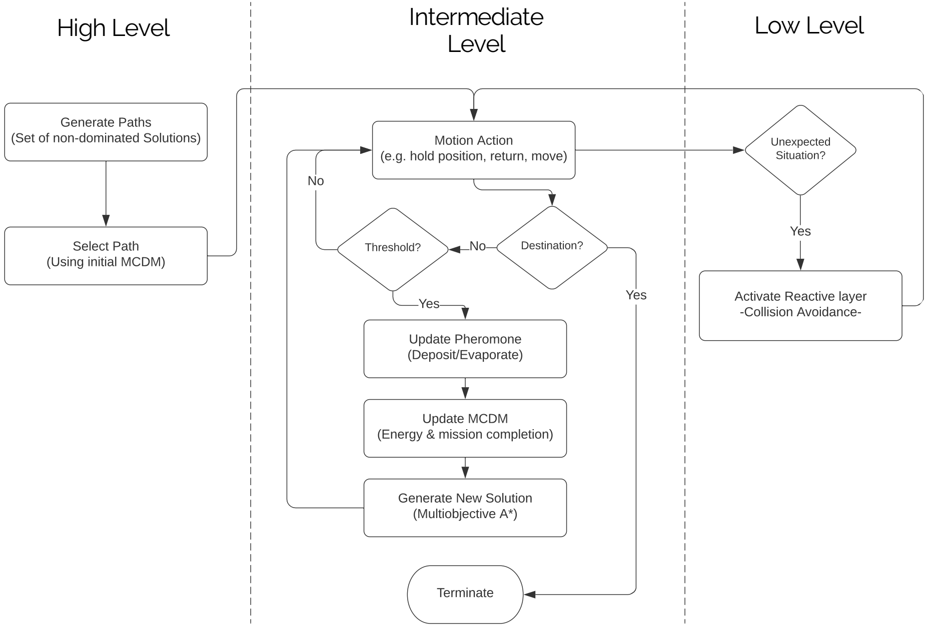
UAV Traffic Optimisation

- ## Stage two – multi-objective optimisation

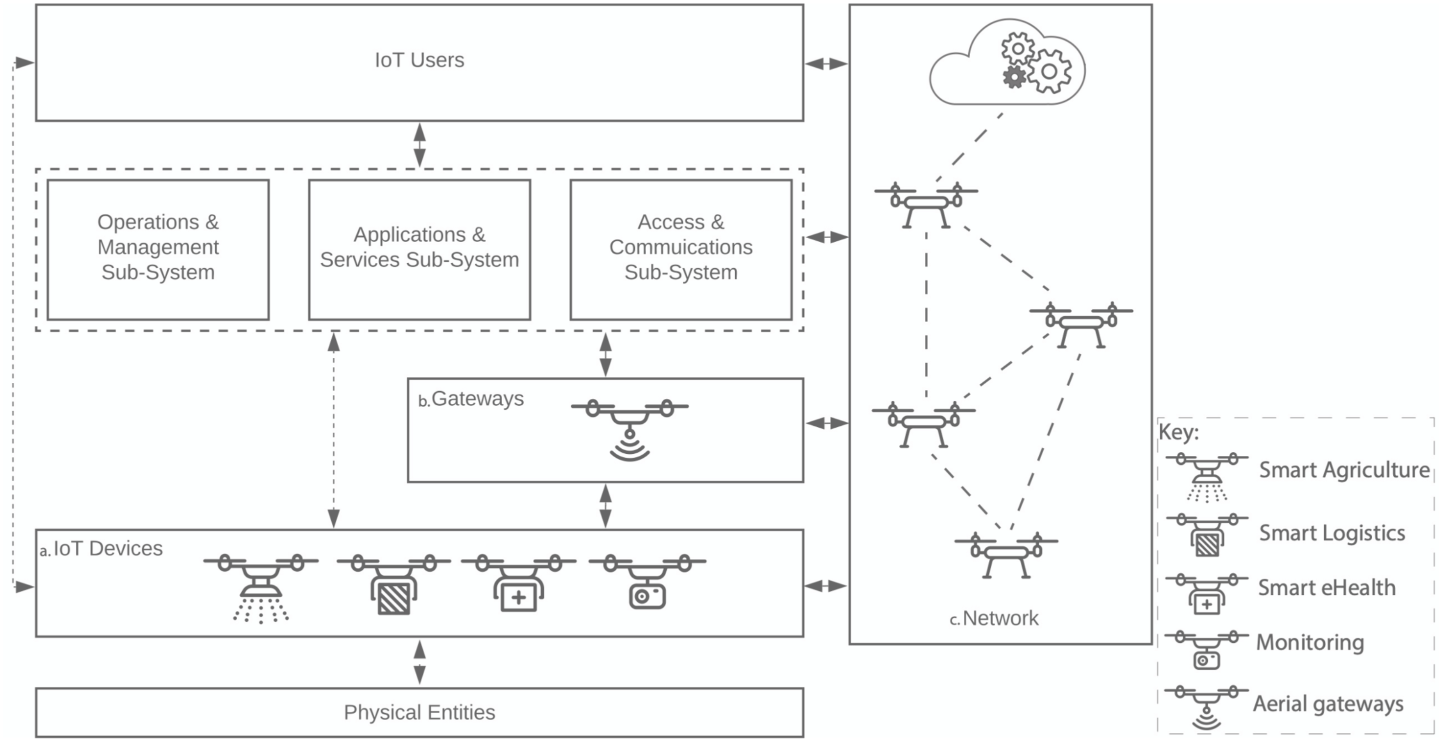
We motivate a multilayer path planning architecture

A novel distributed path planning algorithm for autonomous UAVs

- Initial global planner (not dynamic)
- A dynamic responsive multiobjective path planner
- A dynamically updated Multi-Criteria Decision Matrix
- Relying on pheromone model - extended Local Pheromone Guided (eLPG).

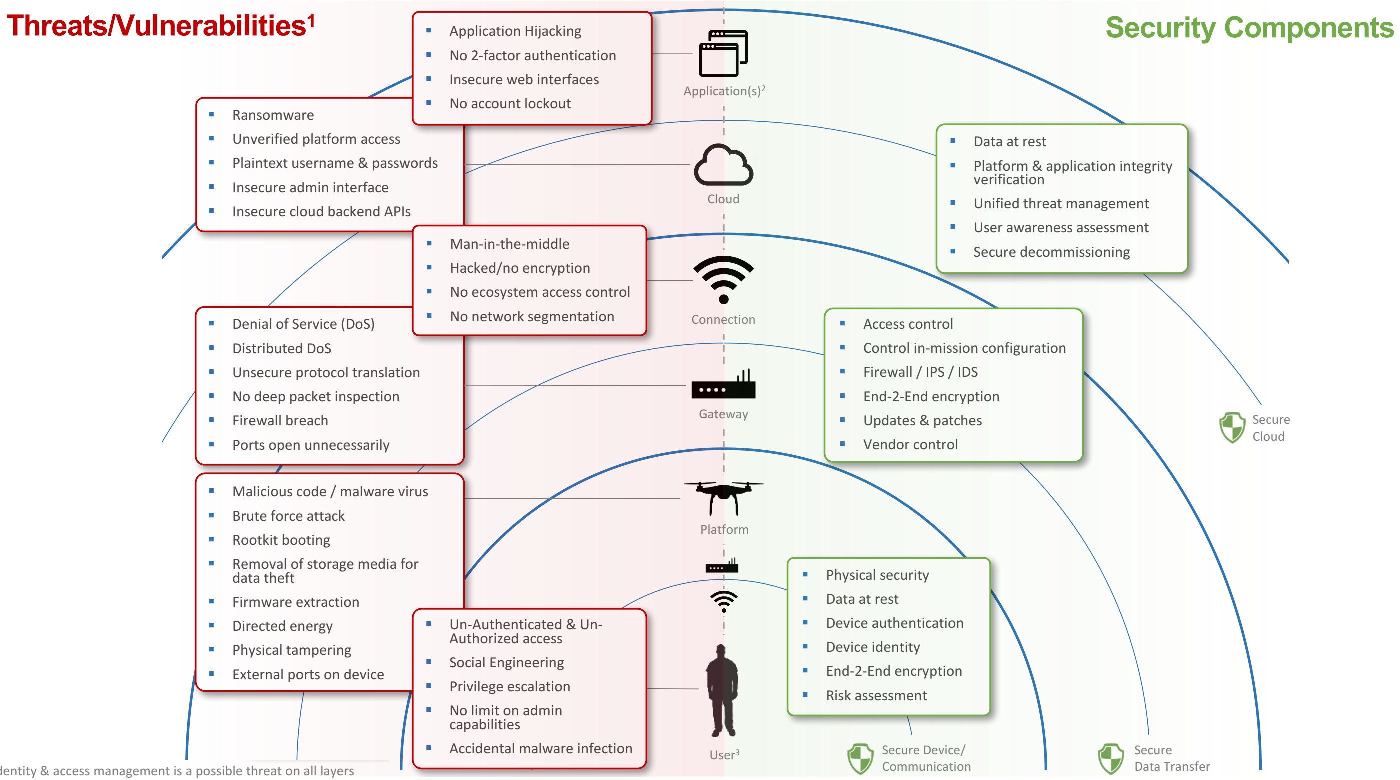


UAVs in IoT – Recap



S. Labib, N.; Danoy, G.; Musial, J.; R. Brust, M.; Bouvry, P. Internet of Unmanned Aerial Vehicles: A Multilayer Low-Altitude Airspace Model for UAV Traffic Management. Sensors, 2019.

Data Protection Privacy and Security



[1] Attacks on identity & access management is a possible threat on all layers
[2] e.g.: CRM, ERP, SCM, PLM
[3] User: can represent a person, device, process, application or system

Closing Remarks

- **Potential**

IoT is already a reality and it is taking the aerospace industries by the storm, allowing for new value-added services, applications and enhanced customer experience.

- **Challenge**

The required technical standards yet lag behind what is being deployed, making it relatively easy to develop and adopt non-standardized IoT and UAV systems.

- **Opportunity**

Adopting or endorsing evolving standards is not only an effective way of showing commitment and promoting an open approach, it allows early adopters the opportunity to shape technical standards, creating additional revenue by promoting patented intellectual property and preferred technical approaches.

Summary of Contributions

[1] N. S. Labib, M. R. Brust, G. Danoy, and P. Bouvry, “On Standardised UAV Localisation and Tracking Systems in Smart Cities,” in Proceedings of 17th STS Conference on Critical Issues in Science, Technology and Society, Graz 2018.

[2] White Paper: Data Protection and Privacy in Smart ICT-Scientific Research and Technical Standardization. Technical report, UL-ILNAS, 2018.

[3] N. S. Labib, M. R. Brust, G. Danoy, and P. Bouvry, “Trustworthiness in IoT - A Standards Gap Analysis on Security, Data Protection and Privacy,” in Proceedings of IEEE Conference on Standards for Communications and Networking (CSCN), Oct 2019. doi:10.1109/CSCN.2019.8931393

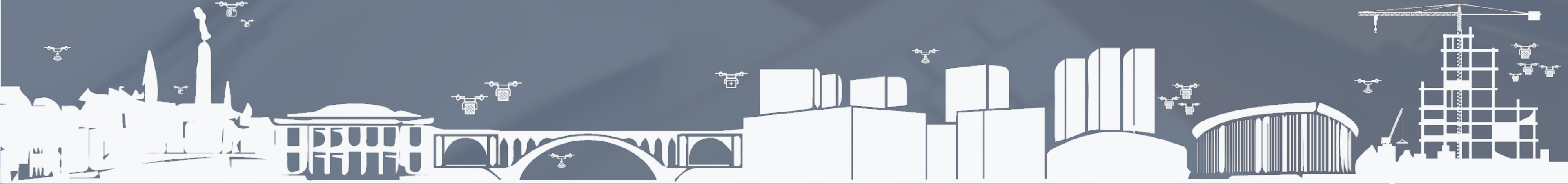
[4] Technical Report: IoT Gap Analysis between Scientific Research and Technical Standardisation. UL-ILNAS, 2019.

[5] S. Labib, N.; Danoy, G.; Musial, J.; R. Brust, M.; Bouvry, P. A Multilayer Low-Altitude Airspace Model for UAV Traffic Management. In Proceedings of the 9th ACM Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications DIVANet’19. ACM, 2019. doi:10.1145/3345838.3355998.

[6] S. Labib, N.; Danoy, G.; Musial, J.; R. Brust, M.; Bouvry, P. Internet of Unmanned Aerial Vehicles: A Multilayer Low-Altitude Airspace Model for UAV Traffic Management. ***Sensors***, 2019, 19(21), 4779; doi:10.3390/s19214779.

[7] S. Labib, N.; Danoy, G.;R. Brust, M.; Bouvry, P. A Distributed Pareto-based Path Planning Algorithm for Autonomous Unmanned Aerial Vehicles (Extended Abstract). WoMAPF IJCAI Jan 2021. ***accepted***

[8] S. Labib, N.; Danoy, G.;R. Brust, M.; Bouvry, P. Unmanned Aerial Vehicles Traffic Management: Intelligent Multiobjective Path Planning for Autonomous UAVs on an Emergency Response Mission. Intelligent Wireless Networks, Sensors. ***in-progress***



Thank you