Centralized and Distributed UTM in Layered Airspace

Leonid Sedov, Valentin Polishchuk
Linköping University
1. Introduction and motivation
ATM reality

Pre-planned airport-to-airport flights

<table>
<thead>
<tr>
<th>Destination</th>
<th>Gate</th>
<th>Time</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARIS</td>
<td>A 43</td>
<td>12:00</td>
<td>ON TIME</td>
</tr>
<tr>
<td>FRANKFURT</td>
<td>A 15</td>
<td>12:10</td>
<td>ON TIME</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>B 08</td>
<td>12:25</td>
<td>ON TIME</td>
</tr>
<tr>
<td>BRUSSELS</td>
<td>A 21</td>
<td>12:30</td>
<td>ON TIME</td>
</tr>
<tr>
<td>ROME</td>
<td>A 30</td>
<td>12:30</td>
<td>ON TIME</td>
</tr>
<tr>
<td>BOSTON</td>
<td>B 01</td>
<td>12:35</td>
<td>ON TIME</td>
</tr>
<tr>
<td>LONDON</td>
<td>A 19</td>
<td>12:40</td>
<td>ON TIME</td>
</tr>
<tr>
<td>RIO DE JANEIRO</td>
<td>B 13</td>
<td>12:45</td>
<td>ON TIME</td>
</tr>
<tr>
<td>MADRID</td>
<td>A 26</td>
<td>12:45</td>
<td>ON TIME</td>
</tr>
<tr>
<td>ATHENS</td>
<td>A 37</td>
<td>12:50</td>
<td>ON TIME</td>
</tr>
<tr>
<td>STOCKHOLM</td>
<td>A 40</td>
<td>13:00</td>
<td>ON TIME</td>
</tr>
<tr>
<td>DUBLIN</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
UTM designer dream (NASA, Ectl ConOps)

= ATM reality

- All know all
- Centralized system
- Flightplans submitted
- Conflicts checked
- Conflicting flightplans delayed
  (Ground Delay Program)
UTM designer dream (NASA, Ectl ConOps)

= ATM reality

- All know all
- Centralized system
- Flightplans submitted
- Conflicts checked
- Conflicting flightplans delayed
  (Ground Delay Program)

COMM\text{on UN}\text{manned Integrated System Management}

COMMUNISM
UTM ≠ ATM

<table>
<thead>
<tr>
<th>Model</th>
<th>Boeing 747-400</th>
<th>DJ Phantom 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max # of passengers</td>
<td>660</td>
<td>0</td>
</tr>
<tr>
<td>Speed</td>
<td>982 km/h</td>
<td>72 km/h</td>
</tr>
<tr>
<td>Weight</td>
<td>184.567 kg</td>
<td>1.4 kg</td>
</tr>
<tr>
<td>Length x Width x Height</td>
<td>70,60 m x 64,44 m x 19,41 m</td>
<td>0,32 m x 0,38 m x 0,22 m</td>
</tr>
<tr>
<td>Requires runway</td>
<td>✔️</td>
<td>✗</td>
</tr>
</tbody>
</table>
Drone aerodromes
Flexibility where possible, structure where necessary
2. Airspace designs
All drones occupy the same altitude

Single-layer design
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Ground Delay
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Ground Delay
The animated version of this slide is available online - https://tinyurl.com/icrat18utm

Ground Delay
Airborn delay (hovering)

The animated version of this slide is available online -
https://tinyurl.com/icrat18utm
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Airborn delay (hovering)
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Airborn delay (hovering)
The animated version of this slide is available online - https://tinyurl.com/icrat18utm

Airborn delay (hovering)
Multi-layer design
Something similar to “Layers” in Metropolis project →
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Layer assignment
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm
Layer assignment
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Layer assignment
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Descending
The animated version of this slide is available online - https://tinyurl.com/icrat18utm
Descending
The animated version of this slide is available online -
https://tinyurl.com/icrat18utm

Descending
Conflict resolution algorithms

<table>
<thead>
<tr>
<th></th>
<th>Single-layer</th>
<th>Multi-layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized</td>
<td>Ground delay</td>
<td>Layer assignment</td>
</tr>
<tr>
<td>Distributed</td>
<td>Hovering</td>
<td>On-demand descending</td>
</tr>
</tbody>
</table>
# Single- vs Multi-layer

<table>
<thead>
<tr>
<th>Single-layer design</th>
<th>Multi-layer design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited need in airspace</td>
<td>The airspace is limited</td>
</tr>
<tr>
<td>Loss of efficiency</td>
<td>No loss of efficiency</td>
</tr>
</tbody>
</table>
3. Simulation
Instantiation

Cal model

- [Bulusu, Sengupta, Liu (Berkeley) @ ICRAT'16]
- [PK (NASA's UTM PI) @ Google: "every home will have a drone and every home will serve as an aerodrome"]
UAV = disk
Ground Delay: Direct flight

Figure 3 from [Bulusu, Sengupta, Liu (Berkeley) @ ICRAT'16]
Hovering
Layer assignment

UAV in transit

ascent

origin

descent

destination
Layer assignment == Graph coloring

Nodes = UAVs
Edges = conflicts
Colors = layers
Descending

UAV in transit
layer change

ascent
origin
descent
destination
Input

- Population density map
- Expected number of flights $N$
- Radius $r$ of UAV
4. Results
Average extension of travel time

Centralized (ground delay)

Decentralized (hovering)
Ground Delay
Percentage of UAVs lost > 10% of time

Centralized (ground delay)

Decentralized (hovering)
Delay probability

Almost the same for hovering
Number of layers used

Number of layers used, layer assignment algorithm

Number of layers used, on-demand descending

Centralized (layer assignment)

Decentralized (descending)
Distribution of drones

Distribution of drones among layers, layer assignment algorithm

Centralized (layer assignment)

Distribution of drones among layers, on-demand descending

Decentralized (descending)
% of UAVs in a vertical collision, hovering
% of UAVs in a vertical collision, layer assignment
% in a vertical collision, on-demand descending

+ the same collisions as in layer assignment
What if we distribute drones among layers based on heading direction?
5. Conclusion and further work
Conclusion

Is centralized always better?

Understand UTM automation level
How central should UTM be?

Mantras

- Flexibility where possible, structure where necessary [PK et al, NASA ConOps]
- When technology is right, regulation is light [F. Schubert, Skyguide CCO]
Further work

● Limit the number of layers
● Other coloring
  ○ Sum coloring
  ○ Balanced coloring
  ○ Equitable coloring
● Other deconfliction strategies
Further work

- Limit the number of layers
- Other coloring
  - Sum coloring
  - Balanced coloring
  - Equitable coloring
- Other deconfliction strategies