Multi-drone four-dimensional flight constraint management

Abstract

With the emergence of the unmanned aerial vehicle (UAV) eco-system for commercial and enterprise markets, multi-drone traffic management has become critical to ensure efficiency and safety of airspace. Guidelines[1] pertaining to unmanned traffic management (UTM) are being drafted, encompassing air traffic control, detect, sense, and avoid (DSAA) technology, 3D flight planning, and flight safety with geo-fencing and no-fly zones.

Introduction of autonomous drones catering to multiple market segments across telecom, retail, manufacturing, transportation, healthcare, and public safety mandates a more robust traffic management approach. While three-dimensional airspace management includes novel approaches such as sky-lanes and sky-corridors, additional four-dimensional (airspace and time) flight constraints monitoring and mitigation is critical to enable collision-free and safe flights.

This paper focuses on an autonomous approach to resolve 4D constraints. It takes into consideration that the original flight plan of the multi-drone eco-system is not churned during 4D constraints resolution. This is an important value-add, as 3D conflict resolution usually involves deviation from the planned flight path.

Trends and Challenges

The addressable market for a consolidated drone ecosystem is expected to grow to $127 Billion by 2020.[2] This exponential rise is being driven by rapidly evolving drone technologies that power new business and operating models. Use cases employing drone technology span multiple industries, where drones are being integrated with existing business processes, enabling 'Drone-as-a-Service.'

As the ecosystem evolves and drones are widely deployed, the need for effective airspace management also becomes important. In the manned airspace, air traffic control (ATC) manually caters to and resolves the 4D constraints. However, in the UAV ecosystem with multiple drones, manual intervention would be time-consuming and prone to human-error, and is not an optimal solution. An autonomous approach to monitor, detect, and mitigate 4D conflict would be the preferred and recommended approach for streamlined UAV traffic management.

Advancements in technology are already powering autonomous and beyond visual line of sight drones (BVLOS) flights that would be leveraged for Drone-as-a-Service. Individual UAV service suppliers (USSs) would coordinate with UTM providers for flight plan verification, approvals, and real-time monitoring. While the flight plans get validated for airspace, flight path and no-fly zone conflicts, 4D constraint monitoring and mitigation will be essential to enhance the safety and service effectiveness of autonomous or BVLOS drones.

Approach

Let us consider a use-case where independent UAV service suppliers are delivering Drone-as-a-Service for retail-delivery at an enterprise. While the individual flight plans are pre-approved by UTM, airspace and time constraints could be encountered.

Imagine a scenario where two packages, one containing medical supplies and the other with corporate letters from different USSs, are arriving at the same time at a company's designated landing zone.

While each of the above services needs to be executed, the conflict must be tackled to ensure that the USSs are successful in delivering the packages and meeting their SLAs.

We present an approach to monitor and resolve these 4D constraints by employing a localized, multi-drone airspace manager. The airspace manager is a setup of ArduCopter[3] and MAVlink[4], representing multiple USSs in the ecosystem, to which the ground control is integrated through open REST APIs using ICAROUS[5].

The approach takes into consideration the existing recommendations of UTM applicable for USSs, and implements a modular plugin, incorporating application logic and interface to USSs to manage the 4D constraints.

Monitor, Detect, and Mitigate

The approach has been designed for a localized multi-drone eco-system, where multiple USSs are providing Drone-As-A-Service. In this use case, we have considered USS-1 delivering critical medical supplies and USS-2 delivering standard corporate letters at the enterprise's designated landing zone.

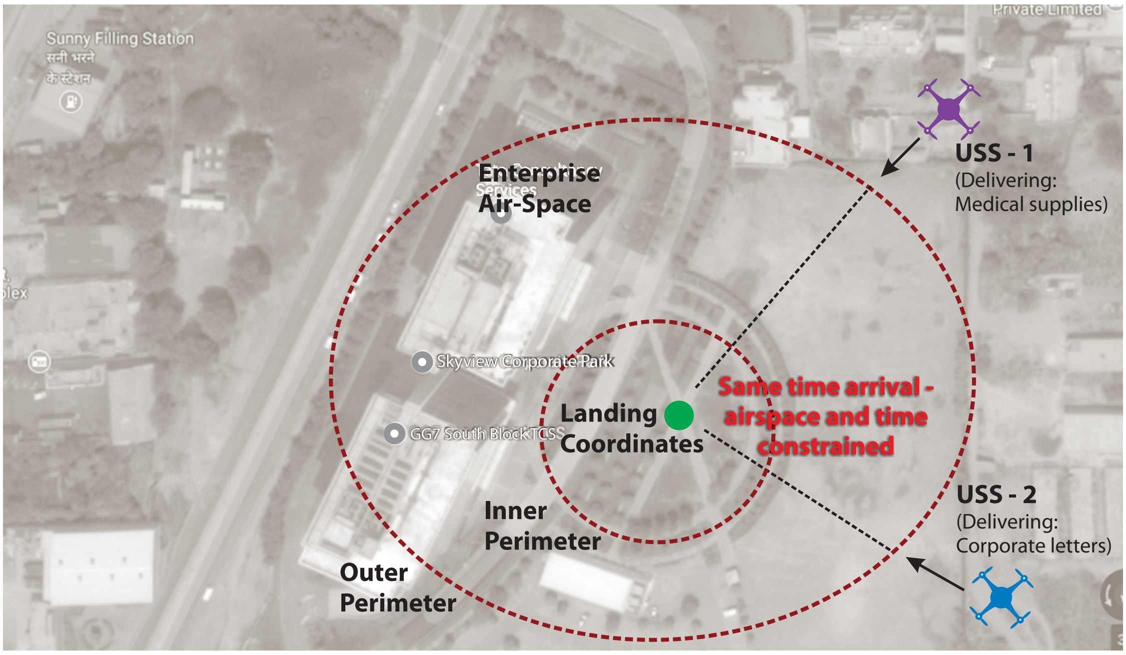

Figure 1- Multi-Drone Ecosystem: Retail Delivery Scenario

The modular plugin implemented for the approach validation is integrated with the discussed airspace management solution. The solution registers and starts monitoring the drones once they enter the enterprise's outer perimeter, and computes the possibility of a 4D conflict between the independent USS' drones.

If such a constraint is detected, the solution works with the USS' UTM system to take into consideration additional flight parameters- service prioritization, service type, payload type, and drone telemetry data. It then uses the pre-defined business logic to recommend the mitigation plan to the USS' drones –loiter within the inner perimeter or proceed to fly to the landing zone. The independent USSs are directed to execute the mitigation plan, thus resolving the 4D constraint. Post conflict resolution, the drones proceed with the approved flight paths.

The key tenet of the approach is that the original approved flight path of the USS' drone is not altered to manage the airspace and time conflict.

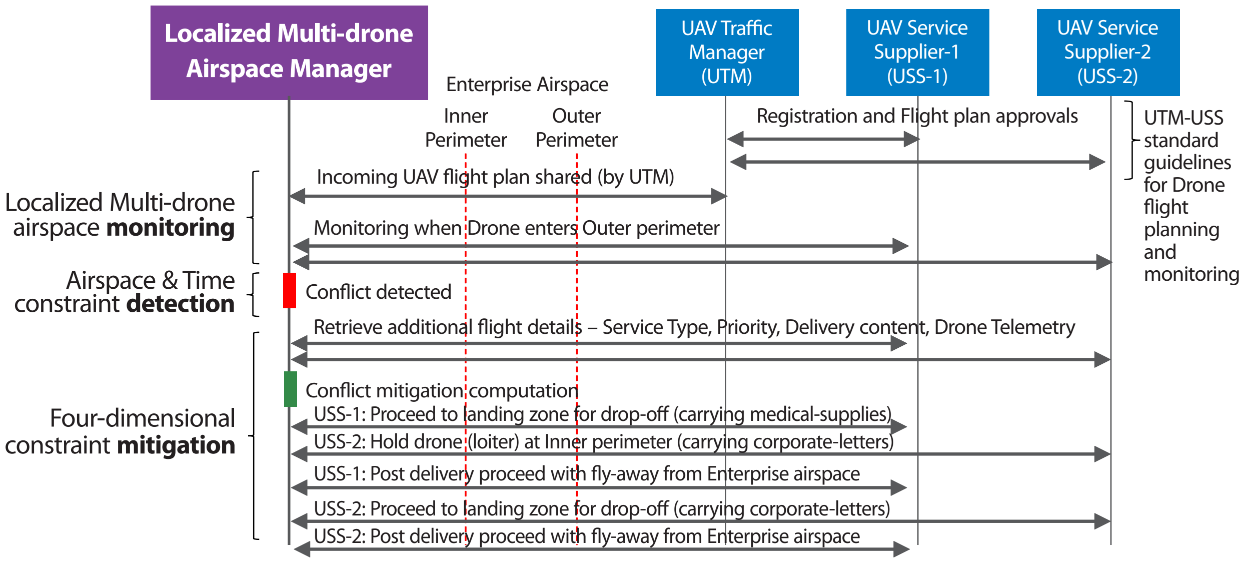

Figure 2 – Multi-Drone 4D Flight Constraint Management

Additional features that can be implemented include:

- Autonomous BVLOS/UAV positioning using GPS, wireless triangulation and drone telemetry
- Geo-fence markup and consideration
- Proximity alerting, in case the UAV is nearing a no-fly zone
- Exigency support to enable safe landing of the UAVs in the localized air space, within the outer perimeter
- Open interface to support the integration with UTM and USS

The proposed approach and the integrated solution would drive agility in drone services across multiple industry segments. Here are some possible deployments where 4D constraint mitigation would help deliver effective Drone-as-a-Service:

- **Enterprises:** Localized multi-drone airspace management
- **Retail:** Commercial establishment enabling on-time delivery or pick-up

- **Public safety:** Multi-USS collaboration
- **Healthcare:** Cohesive operations for emergency response, and search and rescue operations
- **Entertainment:** Live streaming
- **Telecom:** Cell on wings (COW), on-demand network - Wi-Fi, wireless

Roadmap – Next steps

The discussed approach is desirable for localized multi-drone airspace management, ensuring autonomous, agile 4D constraint monitoring, detection, and mitigation.

While this paper demonstrates the recommended approach for 4D constraint management, there is scope for additional enhancements to tackle more complex conflicts. Some of these are:

- **Fleet management:** Provide Drone-as-a-Service, leveraging a fleet. Within the fleet, the respective USS would handle constraints, and across independent USSs, four-dimensional constraints would be monitored and resolved.
- **Security considerations:** Detect rouge UAVs and trigger alerts
- **Regulatory guidelines:** Include deployment specific guidelines that would be applicable for an enterprise or industry. For instance, in a public safety use-case, law enforcement and medical care UAVs will get prioritization over news-reporting UAVs
- **AI enablement:** Deploy an intelligent model to replace the existing rule-based model, taking into consideration multiple flight parameters while deciding on the conflict mitigation approach

References

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