A3P: Advanced Airspace Availability Protocol for Dynamic and Trusted Drone Operations in Smart Cities

Andre Elias Melo[1,3], Flavio Luiz dos Santos de Souza[1,2,4], Rafael Hickmann Albarello[1,3], Rodrigo Sergio dos Santos Nunes[1], Andrei Gurtov[2], Carlo Henrique Ribeiro[1], Cesar Marcondes[1] and Lourenço Alves Pereira Junior[1]

[1]Aeronautics Institute of Technology – ITA – Sao Jose dos Campos, SP – Brazil
[2]Linköping University – LiU – Sweden
[3]Airspace Control Institute – DECEA/FAB – Brazil
[4]Federal Institute of Sao Paulo – IFSP – Catanduva, SP – Brazil

andre.melo@ita.br,flavio.souza@ifsp,{albarello,rodrigosergio}ita.br
andrei.gurtov@liu.se,{carlos,cmarcondes,ljr}@ita.br

Abstract. *A3P is a protocol designed to address the challenge of disseminating dynamically changing information about available airspace portions to Unmanned Aircraft Systems (UAS). It proposes a secure, low-latency, and scalable approach using direct wireless broadcast and distributed systems. A3P introduces Airspace Status Beacons, signed messages compatible with DRIP and ASTM standards. The protocol incorporates cryptographic trust frameworks, federated sensor validation, and resilience-enhancing mechanisms. A3P is being developed and evaluated by an international working group involving academia and industry to contribute to standardization and regulatory discussions.*

Resumo. *O A3P é um protocolo desenvolvido para enfrentar o desafio de disseminar informações dinâmicas sobre porções disponíveis do espaço aéreo para Sistemas de Aeronaves Não Tripuladas (UAS). Ele propõe uma abordagem segura, de baixa latência e escalável, utilizando transmissão sem fio direta e sistemas distribuídos. O A3P apresenta os Airspace Status Beacons, mensagens assinadas compatíveis com os padrões DRIP e ASTM. O protocolo incorpora estruturas de confiança criptográfica, validação federada de sensores e mecanismos de aprimoramento de resiliência. O A3P está sendo desenvolvido e avaliado por um grupo de trabalho internacional que envolve a academia e a indústria para contribuir com as discussões sobre padronização e regulamentação.*

1. Introduction

Drones and electric Vertical Take-off and Landing (eVTOLs) are transforming urban logistics, emergency response, and mobility [Aposporis 2024, Wang et al. 2023]. The integration of these vehicles in urban airspace requires not only regulatory compliance and real-time identification [ASTM 2021], but also a robust framework for dynamically managing the availability of the airspace itself. However, traditional approaches based on static restrictions and centralized data are insufficient for the operational realities of modern cities [FAA 2018, ASTM 2021]. These environments present rapidly changing airspace conditions due to temporary events, intermittent heliport operations, and dynamic safety constraints that are not captured by static models.

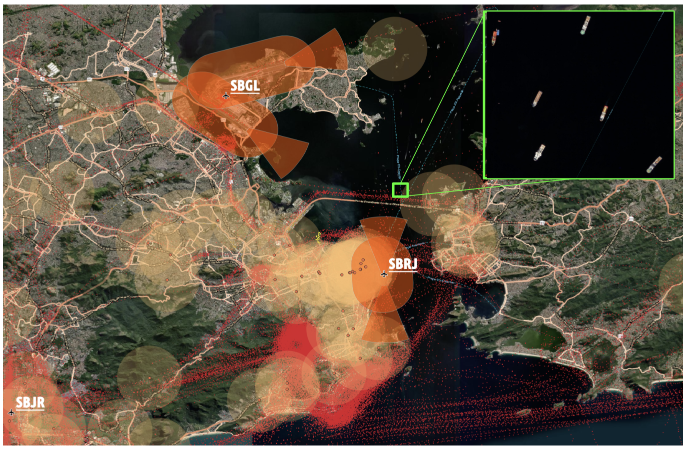

Figure 1. A Visualization of FRZs in a Metropolitan Scenario.

To address these challenges, international bodies have established foundational frameworks. The International Civil Aviation Organization (ICAO) has set global principles for UAS Traffic Management (UTM), aiming to harmonize operational rules and promote the safe integration of drones into manned airspace. In parallel, the American Society for Testing and Materials (ASTM) has developed technical standards, such as *ASTM F3548* for UAS Service Supplier (USS) interoperability and *ASTM F3411* for Remote ID and tracking, enabling standardized information exchange between operators, authorities, and airspace users. The Internet Engineering Task Force (IETF), through working groups such as Drone Remote Identification Protocol (DRIP)[1], has provided technical specifications for cryptographically secure drone identification and protocols for distributed, trusted information sharing.

Despite these efforts, a gap remains in the secure and real-time dissemination of airspace availability. Urban airspace is often governed by fixed, conservative restrictions—such as heliport protection Flight Restriction Zones (FRZs), temporary no-fly areas, and military corridors—that remain active regardless of actual operational needs (see Figure 1). Such constraints are rarely updated in real-time, leading to underutilized air corridors and hindering innovation in drone-based eVTOL services. Figure 1 depicts a representative metropolitan area, highlighting how overlapping static and mobile constraints—such as helicopter activity and restricted maritime zones—drastically reduce the operational airspace. The cumulative impact of fixed and dynamic constraints emphasizes the urgent need for protocols that disseminate fine-grained airspace availability to enable safe and flexible Uncrewed Aircraft (UA) operations.

Existing frameworks, such as the Discovery and Synchronization Service (DSS) [ASTM 2021] and Remote ID [ASTM 2021], provide mechanisms for identifying drones and sharing static restriction information, but do not offer a standard for broadcasting or securely sharing dynamic and trusted updates of the current status of restricted airspace volumes. This limitation constrains real-time situational awareness, hindering coordination between authorities, Unmanned Aircraft System (UAS) operators, and service providers, particularly in dynamic or degraded connectivity scenarios, as well as operational resilience and route optimization in urban settings.

[1] `https://datatracker.ietf.org/group/drip/`

An interoperable and secure protocol is needed—supporting both local broadcast (RF/WiFi) and networked dissemination (DSS/UTM)—to bridge this gap and support urban drone operations. This dual-mode capability is essential for enabling responsive, data-driven airspace management in smart cities, thereby unlocking the full potential of Advanced Air Mobility (AAM).

2. Motivation and Problem Statement

The deployment of drones and eVTOLs in urban airspace is often restricted by management practices that do not reflect real usage patterns, as shown in Figure 1. Static airspace rules often remain in effect, regardless of real-time activity (e.g., inactive heliports or periods of low traffic), leading to inefficient use of the lower airspace and hindering the expansion of urban drone services. Additionally, dense metropolitan areas present mobile and time-sensitive constraints—such as helicopter corridors, vessel traffic, and event zones—that cannot be captured by static models alone. The inability to dynamically update the operational status of airspace volumes creates unnecessary routing restrictions and prevents stakeholders from making context-aware, data-driven decisions.

Existing frameworks offer identification and static restriction sharing but lack mechanisms for broadcasting or federating timely and trustworthy updates about dynamic airspace availability. This results in limited situational awareness and delays in decision-making, particularly in time-critical or connectivity-limited contexts. However, advances in AI and predictive analytics are making dynamic and optimized airspace management increasingly feasible, allowing for new opportunities in adaptive airspace usage, such as the temporary reallocation of inactive heliport zones or low-priority corridors.

Recent research has advanced dynamic airspace management for AAM. [Li et al. 2021], for example, presents solutions for event-driven scenarios; however, their work focuses on localized event handling rather than interoperable, broadcast-based architectures suitable for city-scale integration. Wang et al.(2023) emphasize the importance of real-time data and integration, but do not propose a standardized protocol to support local broadcast. Aposporis(2024) reviews global frameworks and identifies gaps; however, there is no concrete implementation that offers dual dissemination modes and security primitives for broadcast airspace updates. Thus, despite progress, there remains a need for an open and extensible protocol that supports both networked and broadcast dissemination of airspace status.

As seen in DRIP and related standards [Moszkowicz et al. 2021, Card et al. 2023, ASTM 2022, ASTM 2021], dual-mode protocols—enabling both broadcast and networked dissemination—significantly enhance situational awareness and flexibility. The literature highlights broadcast mode for direct, real-time updates—essential when connectivity is unreliable or during emergencies—while networked mode integrates updates into broader UTM and smart city systems, supporting ongoing tracking and compliance. Combining both, as recommended in recent guidance, is key to robust, scalable UAS and AAM integration in diverse operational contexts.

These limitations highlight a clear research and engineering gap: a need for a secure, interoperable, and trust-aware protocol for sharing airspace status in real-time, through both networked and broadcast channels. Such a solution must also address operational trust (e.g., authenticated broadcasters), resilience to spoofing or jamming, and compatibility with UTM standards, enabling practical adoption in smart cities and regulated airspaces. These gaps motivate the development of the Advanced Airspace Availability Protocol (A3P), a protocol designed to overcome these limitations by enabling the timely, secure, and dual-mode dissemination of airspace availability in a standardized and interoperable manner.

3. Proposed Solution: The A3P Protocol

The A3P addresses this gap by standardizing the real-time sharing of airspace availability for restricted, reserved, or managed airspace volumes. A3P defines:

- **Dynamic Status Broadcast**: Each protected asset (e.g., heliport, event area) can broadcast its current status, using signed beacon messages with temporal validity. These beacons include digital signatures using Cryptography (e.g., ECDSA over P-256 or Ed25519) to ensure authenticity and prevent spoofing. The choice of lightweight asymmetric algorithms strikes a balance between security and performance for constrained airborne devices, as demonstrated by [Khan et al. 2023]. Signature verification is mandatory before processing updates, which mitigates replay attacks. Keys are managed through a hierarchical trust model inspired by DRIP, where broadcast nodes must possess a pre-assigned certificate issued by an authorized UTM authority.
- **Network Synchronization**: Status updates are also published through UTM networks, leveraging DSS or compatible APIs, which enables synchronization across service providers, authorities, and stakeholders. These updates are secured and timestamped to ensure consistency and trust.
- **Authentication and Security**: All broadcast and network messages follow a lightweight security scheme based on signatures and timestamp validation, compatible with DRIP. Trust management of authorized broadcasters is supported via certificate chains or pre-registered keys [Alkatheiri et al. 2022].
- **Extensible Data Model**: A3P supports various airspace restriction types (e.g., FRZ, heliports, events), and includes metadata such as validity duration, priority class, geolocation, and issuer authority ID.

Typical use cases for network-based dissemination include: **(i) Routine Operations:** UTM providers receive live updates on available corridors and temporary no-fly zones, optimizing drone routing for delivery, inspection, or public safety missions. **(ii) Large Public Events:** Authorities broadcast temporary restrictions and operational windows for sporting events, concerts, or festivals, ensuring that all commercial and governmental operators are synchronized and compliant. **(iii) Urban Planning and Public Works:** Updates regarding airspace closures or opening for major construction sites, roadworks, or infrastructure inspections can be shared with all stakeholders, reducing operational conflicts and improving efficiency. **(iv) Integration with Sensor Federations:** Multiple smart city sensors or federated observers contribute to a common operating picture, increasing reliability and redundancy in airspace management.

The broadcast mode enables direct and local dissemination of airspace status, particularly valuable in areas with intermittent or no network connectivity. This is especially important for operational resilience in scenarios where the network is unavailable or overloaded, or where on-the-fly decisions must be made at the tactical edge. Use cases where broadcast dissemination is particularly valuable include:

- **Emergency and Disaster Response**: In the aftermath of a natural disaster, drones deployed for search and rescue can receive local airspace updates directly via RF or WiFi, even if communication infrastructure is disrupted.
- **Temporary Barriers and Mobile Restrictions**: Law enforcement or emergency responders can quickly establish pop-up no-fly zones in the vicinity of unfolding incidents, with broadcasted messages instantly received by nearby UAS and eVTOLs.
- **Operation in Remote or Congested Areas**: Drones operating in areas with limited or unreliable connectivity, such as rural construction sites or heavily congested urban zones, can still obtain up-to-date airspace status through local broadcasts.
- **Large Public Gatherings**: During parades, political rallies, or street festivals, local broadcast ensures that drones entering the vicinity are immediately aware of dynamic restrictions, even if they are not registered with a central UTM system.

By combining networked and local broadcast dissemination, A3P ensures context-aware and fault-tolerant airspace awareness, even under degraded communication or cybersecurity conditions. This dual-channel strategy supports scalable and resilient airspace coordination across diverse urban scenarios, helping to maximize safety, mission flexibility, and regulatory compliance. Unlike existing frameworks that focus on either centralized DSS or ad-hoc broadcast signaling, A3P offers a unified, secure, and extensible approach that supports both modalities in a fully interoperable architecture. This dual-mode design—backed by DRIP primitives and operational trust management—enables seamless integration with existing UTM services while allowing for tactical edge awareness in disconnected or emergency contexts.

4. Reference Architecture and Integration

Figure 2 presents the high-level architecture of the A3P, which enables the dissemination of airspace status information through both networked and broadcast channels in urban environments. This architecture connects key actors (e.g., operators, observers, UTM systems) and trusted technical components, aiming to maximize situational awareness, operational resilience, and secure integration of UAS and eVTOL operations. As illustrated in Figure 2, A3P's architecture maps the dissemination flows and trust domains between operators, sensors, USS/DSS systems, and aerial agents.

At the core of the architecture are event and critical infrastructure operators, such as heliports, stadiums, and refineries, which serve as primary sources of real-time airspace status updates. These entities are responsible for initiating status changes, such as marking a heliport as inactive or introducing a temporary restriction due to a public event. Each update is digitally signed and includes metadata, such as volume location, Time-To-Live (TTL), and restriction type. Operators must be pre-authorized through a trust management mechanism. A3P supports two complementary dissemination modalities. In the networked pathway, operators send status updates to UAS Service Suppliers (USS), which communicate with the DSS to register and share this information. The DSS distributes updates to all subscribed USSs, providing UAS operators, regulatory authorities, and sensor networks with synchronized and current knowledge of airspace conditions. This pathway is crucial for coordinated urban air mobility, strategic planning, and airspace deconfliction.

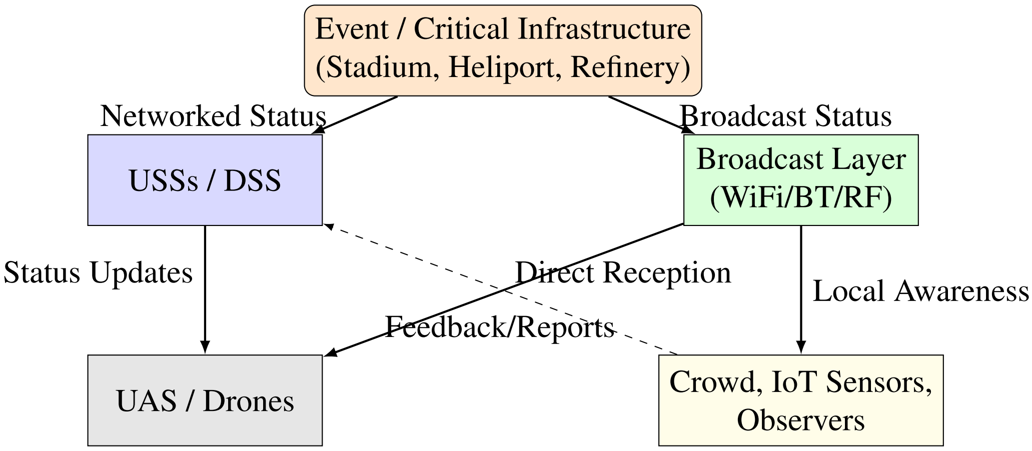

Figure 2. A3P architecture: event operators send airspace status via network (USSs/DSS) and local broadcast (WiFi/BT/RF)

In parallel, A3P enables a broadcast pathway where operators or authorized devices transmit airspace status directly to the local environment using WiFi, Bluetooth, or radio frequency beacons. Drones, eVTOLs, and nearby observers, including the public and distributed Internet of Things (IoT) sensors, can receive these updates in real time, even when internet connectivity is limited or unavailable. This mode is particularly valuable during emergencies, large-scale public events, or major infrastructure projects where immediate local awareness of airspace changes is essential. Broadcast messages also carry digital signatures and may embed DRIP Entity IDs for traceability and spoofing mitigation. Replay protection and expiration checks are enforced by receivers. The inclusion of DRIP Entity IDs in signed beacons ensures traceability and supports receiver-side validation, aligning with RFC 9434 and RFC 9153.

The architecture also incorporates feedback mechanisms, allowing crowd-sourced observers, IoT sensor federations, and ground stations to report local observations or incidents back to USS and authorities. This feedback contributes to trust evaluation and anomaly detection, enabling revocation or reclassification of broadcast zones if tampering or inconsistencies are identified. By combining networked and broadcast dissemination, A3P offers a robust, scalable, and flexible solution for urban airspace management. This approach ensures high availability and redundancy: if DSS connectivity is interrupted, broadcast messages maintain local awareness; if RF channels are degraded, DSS propagation provides strategic continuity. A3P is designed for compatibility with ASTM F3548, F3411, and ongoing IETF DRIP work [ASTM 2021, ASTM 2022, Alkatheiri et al. 2022]. It can be incrementally deployed—starting with key assets (major heliports, stadiums, emergency sites) and expanding city-wide as urban infrastructure and regulation evolve.

5. Preliminary Results and Discussion

We established a validation environment using a realistic scenario in Rio de Janeiro's Guanabara Bay—one of Brazil's most complex urban airspaces, featuring multiple heliports, busy airways, port facilities, and frequent temporary restrictions. Each heliport was configured to broadcast real-time status updates via the A3P protocol, with UTM providers, delivery companies, and public safety agencies subscribing to these updates. This setup enabled real-time opening and closing of protected airspace, safer and more flexible routing, improved regulatory compliance, and increased operational efficiency for logistics and emergency response. To test the concepts of A3P at scale, we integrated our architecture with the InterUSS platform, an open-source implementation maintained by the Linux Foundation that provides DSS capabilities for federated UTM systems. The InterUSS platform allows multiple UTM Service Providers to synchronize operational data securely and efficiently, serving as a backbone for U-space and UTM interoperability.

Preliminary experiments, conducted on a distributed testbed using Hyperledger Fabric and the RNP experimental network, demonstrated potential of the A3P enables secure, low-latency dissemination of airspace status across diverse organizations. The A3P evaluation is based on communication requirements previously analyzed in [Souza et al. 2025], where parameters were defined under various operational conditions. In addition, another experiment, in the final stages of development and submitted for evaluation at an international technical event, was conducted to validate the proposed A3P's safety performance in realistic mobility scenarios. The results corroborate the proposal's viability in terms of scalability, robustness, and compliance with EASA[2] regulations, and will be published in a future article.

The A3P protocol will be developed, implemented, and validated by CGI.br Working Group 4[3], which will contribute to the development of technical standards through the IETF/IRTF. The implementation will involve broadcast modules (Wi-Fi/BLE) and integration with InterUSS, as well as DRIP-compatible security layers. All code and experimental artifacts to be published in a public repository and presented at IETF meetings, ensuring reproducibility. Smart contracts automate compliance checks, while cryptographic signatures provide trust in status updates. Early performance results indicate that the solution is scalable for metropolitan deployments.

Current challenges include onboarding trusted broadcasters, ensuring regulatory harmonization, and implementing privacy-preserving mechanisms for sensitive assets. Ongoing work aims to optimize performance, integrate with DRIP and UTM APIs, and conduct pilot deployments in real-world smart city environments. Following the completion of these studies, we intend to submit a formal RFC to contribute our protocol proposal to the international standards community. While preliminary results validate the feasibility of A3P in metropolitan settings, further work is needed to assess its performance under large-scale scenarios, handle certificate revocation dynamics, define and specify resilience metrics, and ensure compliance with emerging regulatory constraints across different jurisdictions.

6. Conclusion

The development and validation environment established in this work represents a step toward advancing protocols for dynamic and trusted airspace management in urban environments. By leveraging realistic urban scenarios and open-source platforms such as InterUSS, this work validates the feasibility, interoperability, and scalability of A3P in enabling both networked and broadcast dissemination of airspace availability. These results provide evidence that A3P can support dynamic updates from multiple sources, ensure secure information exchange, and enable decentralized airspace coordination — key

[2] https://www.easa.europa.eu/en/downloads/137252/en

[3] https://cgi.br/pagina/chamada-programa-ietf/

requirements for integrating smart cities. This environment also lays the groundwork for collaborative experimentation among regulators, infrastructure owners, and UTM stakeholders, accelerating the development and evaluation of emerging standards, such as DRIP. As next steps, A3P will be piloted in real-world scenarios and submitted as an Internet Draft (I-D) toward formalization within the IETF. Ultimately, A3P contributes to the ongoing maturation of global UTM and AAM protocols, supporting the safe, adaptive, and efficient integration of drones into regulated urban airspaces.

Acknowledgments

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References

Alkatheiri, M. S., Saleem, S., Alqarni, M. A., Aseeri, A. O., Chauhdary, S. H., and Zhuang, Y. (2022). A lightweight authentication scheme for a network of unmanned aerial vehicles (uavs) by using physical unclonable functions. *Electronics*, 11(18).

Aposporis, P. (2024). A review of global and regional frameworks for the integration of an unmanned aircraft system in air traffic management. *Transportation Research Interdisciplinary Perspectives*, 24:101064.

ASTM (2021). ASTM F3548-21: Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability. Technical report, ASTM International, West Conshohocken, PA, USA. Acesso em: 30 mar. 2025.

ASTM (2022). Astm f3411-22a: Standard specification for remote id and tracking. ASTM International.

Card, S., Wiethuechter, A., and Moszkowicz, R. (2023). Drone remote identification protocol (drip) architecture. `https://datatracker.ietf.org/doc/rfc9434/`. RFC 9434.

FAA (2018). Concept of Operations (ConOps). Technical report, Federal Aviation Administration, U.S. Department of Transportation. Acessado em: 17 de Fevereiro de 2025.

Khan, S., Gaba, G. S., Gurtov, A., Mäurer, N., Gräupl, T., and Schmitt, C. (2023). Enhancing cybersecurity for ldacs: a secure and lightweight mutual authentication and key agreement protocol. In *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC)*, pages 1–10.

Li, Y., Ma, Y., Zhao, Y., and Liu, Y. (2021). Uas remote identification and dynamic airspace management for large public events. *Drones*, 5(3):76.

Moszkowicz, R., Wiethuechter, A., Card, S., Gurtov, A., and StJohn, P. (2021). Drone remote identification protocol (drip) requirements and terminology. `https://datatracker.ietf.org/doc/rfc9153/`. RFC 9153.

Souza, F. L., Teixeira, M. A., Ribeiro, C. H. C., and Junior, L. A. P. (2025). Classification and specification of communication network requirements for aavs in military applications. *IEEE Aerospace and Electronic Systems Magazine*, 40(3):4–18.

Wang, L., Deng, X., Gui, J., Jiang, P., Zeng, F., and Wan, S. (2023). A review of urban air mobility-enabled intelligent transportation systems: Mechanisms, applications and challenges. *Journal of Systems Architecture*, 141:102902.