GSMA

Cellular-enabled Aerial Vehicles

Exploration of the Landscape of the North American Ecosystem

Whitepaper

October 2023

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. Our vision is to unlock the full power of connectivity so that people, industry, and society thrive. Representing mobile operators and organisations across the mobile ecosystem and adjacent industries, the GSMA delivers for its members across three broad pillars: Connectivity for Good, Industry Services and Solutions, and Outreach. This activity includes advancing policy, tackling today's biggest societal challenges, underpinning the technology and interoperability that make mobile work, and providing the world's largest platform to convene the mobile ecosystem at the MWC and M360 series of events.

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Term	Description
3GPP	Third Generation Partnership Project specifies 2G-5G networks
4G	Fourth Generation mobile communications system
5G	Fifth Generation mobile communications system
5GC	5G Core Network
5GS	5G System consists of 5G New Radio (NR) and 5G Core (5GC)
AI	Artificial Intelligence
API	Application Programing Interface
BVLOS	Beyond Visual Line-of-Sight
C2	Command and Control data link between the remotely piloted aircraft and the remote pilot station for the purpose of managing flight. Please note: C3 refers to an extended term to cover communications link, too.
CAA	Civil Aviation Authority, e.g., FAA (Federal Aviation Administration) in the USA and EASA (European Union Aviation Safety Agency) in Europe.
DAA	Detect and Avoid
eCAPIF	Enhanced Common API Framework
eNB	Evolved NodeB, 4G radio access element
EPC	Evolved Packet Core, 4G core network
EPS	Evolved Packet System is 4G system that consists of radio and core networks.
E-UTRAN	Evolved UTRAN is the 4G radio network, often referred to as LTE (Long Term Evolution).
FAA	Federal Aviation Administration
FRMCS	Future Railway Mobile Communication System
gNB	Next generation Node B, 5G radio access element
GPSI	Generic Public Subscription Identifier of 5G
IAB	Integrated Access and Backhaul
ID	Identification
I-IoT	Industrial IoT
IoT	Internet of Things
LAA	Licensed Assisted Access
LTE	Long Term Evolution, 4G radio network
M2M	Machine-to-Machine
MIMO	Multiple In Multiple Out antenna technology
MNO	Mobile Network Operator
NAS	National Airspace System

Terminology (continued)

Term	Description
NAVA	North America Vertical Applications Taskforce of GSMA NA
NEF	Network Exposure Function
NF	Network Function
NOMA	Non-orthogonal multiple access
NR	New Radio of 5G
QoE	Quality of Experience
QoS	Quality of Service
ROI	Return on Investment
SA	Service and System Aspects of 3GPP
SBA	Service-Based Architecture
SCEF	Service Capability Exposure Function
SDK	Software Development Kit, collection of software development tools in one installable package
SEAL	Service Enabler Architecture Layer for Verticals
SON	Self-Optimizing Network
TNS	Time Sensitive Networking
UA	Uncrewed Aircraft, typically synonym of UAV or Drone.
UAM	Urban Air Mobility envisions a safe and efficient aviation transportation system that will use highly automated aircraft that will operate and transport passengers or cargo at lower altitudes within urban and suburban areas.
UAS	Uncrewed Aircraft System refers to the combination of the vehicle or aircraft, the controller, and the links that connect them.
UASS ID	UAS Application Specific Server Identifier
UAV	Uncrewed Aerial Vehicle refers to the platform, airframe, or body of the craft. The term can be used interchangeably with Drone and UA.
UAV-C	UAV, Cellular Supported
UE	User Equipment
UNI	User-to-Network interface
URI	Uniform Resource Identifier
URLLC	Ultra-Reliable Low Latency Communications
USS	UAS Service Supplier provides UTM services to support the UAS community, to connect Operators and other entities to enable information flow across the USS network, and to promote shared situational awareness among UTM participants.
UTM	UAS Traffic Management safely integrates manned and uncrewed aircraft into low altitude airspace helping manage traffic at low altitudes and avoid collisions of UASs being operated beyond visual line of sight. UTM architecture is consolidated but its deployment models may differ.
UTRAN	Universal Terrestrial Radio Access Network, 3rd Generation radio access network
UUAA	USS UAV Authentication & Authorization
V2X	Vehicle to Everything
VNF	Virtualized Network Function

Introduction

Target audience

This paper seeks to describe where the cellular UAS market is today in North America, how the mobile networks can support the market today, and cite ongoing activities and open needs to advance the scale of the cellular connected UAS ecosystem for the purpose of supporting commercialization of the core technologies needed to accomplish these tasks.

The intended audience for this paper includes stakeholders in cellular connected and networked UAS ecosystems in North America:

Companies looking to expand their UAS program to include more complex operations may use this as reference for understanding the technical readiness of cellular networks to support the types of operations they seek via UAS.

It is encouraged that this information be used to further ideate, collaborate, and innovate with ecosystem partners to expand commercial adoption and regulatory advancement of cellular networks as a viable economic solution to support the safe integration of UAS in the National Airspace System (NAS) for more complex missions.

UAV Manufacturers	**Supplemental Data Service Providers (SDSPs)**
UAS Manufacturers	**Mobile Network Operators (MNOs)**
Mobile network and device vendors	**Other Communications services providers**
Communications Platform Manufacturers	**Regulators**
Software Developers/ Systems Integrator	**Federal/State/local government users**
UAS Service Suppliers (USS)	**UAS Service Suppliers (USS)**

Why Cellular Networks for Drones?

The use of commercial UAS is growing globally. UASs can perform tasks which may be unsafe or very costly for a human to perform. UASs are a way to get a job done. Those jobs can be simplified into three (3) categories:

The delivery and collection of information

Wide-spread delivery of goods

Looking into the future, the delivery of people

Today, UASs are primarily used to collect data, for photography & video, and limited delivery of goods. Today's UAS use cases are most commonly for short range applications, where the operator is within the line of sight of the UAS. This mode of operation limits the extent to which it can effectively perform the job to be done. Widely available, networked connectivity unlocks capabilities that are not possible or legal today.

Cellular mobile networks are uniquely suited to meet the needs of the network connectivity required for UASs as an emerging industry due to:

- **Low-cost connectivity**
- **Global, standards-driven ecosystem supports the emerging UAS industry**
- **Highly available, low-cost hardware supply & mature supply chains**
- **Accessible technology for new market entrants**
- **Capability for Interoperability & mobility which is critical for UAS market growth**
- **Evolving industry standards that allow for global market expansion and technology road mapping**
- **Delivery of high performance and high security communications services;**
  multiple QoS levels to support a variety of UAS communications needs, per GSMA PRD NG.128 (LTE Aerial Profile) [1]
- **Flexible implementation to meet the needs of various UAS use cases**

The greatest Return on Investment (ROI) for commercial UAS operators is today in long range applications. This means using a communications technology that can enable long distance UAS operations, or those which are beyond the visual line of sight of the operator (BVLOS).

Enabling BVLOS is the first step to enabling scale of commercial UAS programs. This allows one pilot to operate many UASs (1:n), remote deployment of UASs and allows the pilot to control a UAS from anywhere. This increases the human safety factor, reduces the downtime to deployment of assets, and increases the utility of a UAS.

BVLOS and 1:n operations are essential for the scale of the commercial UAS industry.

Today, 4G LTE networks may be used on a UAS to support four (4) primary types of data exchanged to support long range, BVLOS flights:

- Telemetry, including battery percentage, flight direction, speed, etc.
- Sending or Updating Flight Paths via sending coordinates to a UAS.
- Airspace Management Services: This is comparable to Air Traffic Control for planes however, in planes this communication is between a pilot and a controller in a tower. With UASs, there may be no pilot, so the communication is Machine-to-Machine (M2M). These messages may include airspaces alerts such as no fly zones or weather alerts.
- Video and Image streaming: As mentioned previously, commercial UASs are deployed for a business purpose. Today, the most prevalent use of UASs is to deliver data. This includes streaming video and images for purposes such as infrastructure inspection and mapping.

Today, 4G LTE can accomplish a large amount of what is demanded to serve BVLOS & 1:n operations. Even if LTE in current 3-dimensional space may have its limitations, the feasibility of this technology has been demonstrated and cited in multiple studies. [2] [3] [4] This means that stakeholders in the UAS ecosystem can pursue commercial capabilities today; it is encouraged that they do consider beginning now as regulations are rapidly evolving in North America & Globally, opening doors to more opportunities for companies who want to use UAS for their business demand.

The transition from 4G to 5G presents a unique opportunity to recognize new revenue opportunities on legacy technology while advancing our networks to expand and enrich the Quality of Experience (QoE) for UAS applications. Some advantages to 5G for UASs may be:

- **Increased Spectral Efficiency** – 5G deployments can have the ability to reduce interference using MIMO antennas and beamforming.
- **High Density** – 5G deployments can support higher density of aircraft and payload from aircraft.
- **Fully autonomous UAS & Artificial Intelligence (AI)** – 5G may further expand the level of autonomy of the UAS by placing more data intensive capabilities on the wireless link, removing this overhead from the UAS. This may further reduce the cost, weight, and complexity of the UAS.
- **5G URLLC**: Applications requiring very low latency, such as those contributing to Detect and Avoid (DAA).
- **Multi-Access EDGE Computing**: New, flexible architectures may allow for more advanced applications to be hosted on the edge, supporting new network-based service use cases.

GSMA represents the worldwide mobile communications industry and works with industry to provide industry services and solutions. These services & solutions are the underpinning of the technology and interoperability that makes mobile work via global working grounds, projects, services, and promotional activities. [5]

NAVA is a regional task force group activity of the GSMA NA. This group is tasked to resolve regional issues related to the successful establishment and operation of the GSM family of wireless technologies.

NAVA's primary objective is to drive activities which facilitate the market & assist in implementation for ecosystem vendors to commercialize 3GPP technologies for the UAS vertical. NAVA does this through the following:

- engagement with vertical ecosystem on connected, networked UASs
- create deliverable(s) with profile activities which are a work in progress as well as fully specified in 3GPP
- document issues which are not easily or immediately addressable in other interest groups
- identify, flag, and set the stage for resolution to address items blocking commercialization

Though UAS has been compared to IoT for Airborne use, this analogy does not fully address the depth of services which UAS and aircraft utilizing cellular networks will require to fulfill complex operations.

Focus of this whitepaper

This paper will present a summary of key standards organizations and activities which are complete, in progress, and in planning that are essential to support the network connected UAS future. It is highly encouraged that stakeholders consider their place in this ecosystem and understand what dependencies may exist in these standards which can further facilitate their commercial development and provide support and guidance to these activities.

Multiple use cases which have commercial value today will be discussed with reference to real case studies and discussions on how these activities are directly supporting commercialization.

As a central player in this new, distributed, and complex industry, Mobile Network Operators (MNOs) have many opportunities to participate in commercialization of their assets and unique resources. A discussion of potential roles which MNOs may fulfill is provided in the context of what has emerged as a general, globally applicable framework for operational support of a UAS. This introduces how an organization can consider their goals in this market as it relates to regulation, as well as provides a short introduction to UTM concepts.

After a brief discussion on Remote ID, this paper closes with topics which we believe are out of scope at this time, however, should be under consideration today. It is encouraged that these topics and preceding resources are used as a catalyst to start conversations around these issues to discuss valaue, implementation, and commercial opportunities. Participation in NAVA is open to GSMA members and to others participating in the UAS ecosystem and provides a platform for interdisciplinary action in exceling emerging technologies. Contribution is highly encouraged.

Several key resources are provided throughout the text, with the intention to offer a central resource for considering factors which impact the commercialization of mobile network technologies in the emerging UAS market.

3GPP specifications

3GPP Overview for the Non-Technical Reader

The **3rd Generation Partnership Project (3GPP)** is an umbrella term for a number of standards organizations which develop protocols for mobile telecommunications. 3GPP standards are set for cellular networks based on the input of participating members. These standards reflect evolution in technology advancement, as well as the desired use of technology to support new market use cases.

Standardized cellular features are developed in releases (referenced below) which represents a package of new or updated features.

The implementation of these features is at the discretion of the MNO. For commercial users of specific 3GPP features, this is important to understand as no MNO is required to implement 3GPP features, and an MNO may implement a subset of release features to support their desired network operations.

A 3GPP feature may apply to one or more of the cellular network elements: the Core Network (CN), the Radio Access Network (RAN), or the User End-device (UE). If a feature is dependent on more than one element, it must exist in all applicable elements to be implemented. The importance of this interdependency is that these elements are part of an ecosystem which are owned, operated, and developed by different entities. In order for a novel set of 3GPP features to be adopted by industry, it must pose an attractive enough business case to all parties to justify the development, release and maintenance of the network features.

To increase the adoption and aid in implementation of features, standardized profiles are developed by GSMA which offer suggestions as to which features shall be supported together to support a specific market function. An example of this is the implementation of Voice Over IP (VoLTE) profile which enabled a global adoption of VoLTE in a standardized way which enabled roaming and interoperability for consumers. While MNOs are not required to implement such profiles, doing so offers them a blueprint for partaking in a larger business opportunity to support their customers.

As of the writing of the initial version of this paper, the LTE Aerial Profile v1.0 exists but has not been implemented across the cellular ecosystem. The following 3GPP features discussed go into technical detail of the current state of 3GPP work in the UAS space, including features recently developed and those already released. It is imperative that industry partners engage with standards organizations, such as those referenced in the following section, to represent the needs of their emerging business needs to provide cellular ecosystem vendors the insights they need to properly adopt work done by 3GPP and implement the required functions for use by the end user.

The following subsections summarize capabilities of 3GPP releases relevant to the vertical presented in this whitepaper. For specifically UAV and UAS related work items at the 3GPP, see Ref. [6] for key 3GPP resources, study and work items, completed specifications, and a link to the 3GPP workplan for the planned 3GPP work on drones.

ANNEX 1 of this whitepaper summarizes also the key 3GPP work groups and other bodies that may have related aspect to UAV/UAS. Annex 2 presents a UAS application layer functional model that the 3GPP SA6 group has formed.

Release 15

5G System Architecture

The 3GPP Release 15 is the first 3GPP Technical Specification (TS) set that defines the initial 5G architecture and functions for the 5G System (5GS). The 3GPP standardized the Release 15 in 2018, and the respective first phase 5G networks were ready for the commercial markets in the beginning of 2019. In a parallel fashion, the Release 15 also continues developing 4G (Evolved UMTS Radio Access Network, E-UTRAN, and Evolved Packet Core, EPC) and previous generations. 5GS integrates LTE connectivity and interworks with E-UTRAN/EPS. This is an especially relevant aspect for drone operations that are based on cellular connectivity.

One of the main changes in the 3GPP core network architecture for 5GS is the introduction of the new Service-Based Architecture (SBA) as of the Release 15, as well as the first set of virtualized Network Functions (NFs). The new NFs include functions that map with the previous 4G, and it also introduces completely new functions.

5G Release 15 introduces NFs of which one of the most relevant for the verticals' perspective is the Network Exposure Function (NEF). It can provide a platform for creating new services by consolidating APIs and presenting unified access to the API framework for both internal and 3rd party developers. [7]

Furthermore, NEF can provide secure exposure of network services such as voice, data connectivity, and charging, towards 3rd party applications over APIs, as well as a developer environment and Software Development Kit (SDK) for operator and community. Also, NEF enables end-to-end service creation by combining network assets into applications, and an integration layer that connects the applications to an operator's network.

The CAPIF (Common API Framework) was introduced in Rel-15 to enable a unified Northbound API framework across 3GPP network functions, and to ensure that there is a single and harmonized approach for their development and exposure. The framework and architecture are documented in 3GPP TS 23.222. CAPIF ensures that there is single entry point for vertical applications (a.k.a. API invokers) toward the common API aspects (also called CAPIF APIs) such as onboarding, discovery, authentication, and authorization.

Aerial Vehicle Enhancements

The enhancements for 3GPP Release 15 related to aerial vehicles were focused on the EPS architecture and E-UTRAN. A study item in 3GPP RAN created 3GPP Technical Specification TS 36.331 (protocol layer of LTE Radio Resource Control) in its Section 5.5.4 (measurement report triggering), and in 3GPP TS 23.401 (General Packet Radio Service enhancements for E-UTRAN).

Release 15 work for aerial vehicles introduced the following enhancements:

Aerial vehicles authorization: TS 23.401 introduces the UE aerial subscription and indication, which allows the system architecture to identify which 3GPP UEs have an aerial subscription, and allows the core network to activate the UE aerial features defined for aerial UEs only for UEs that have an aerial subscription.

The aerial UE features introduced in TS 36.331 provide LTE enhancements to address the issue of aerial UE interference with the base station (eNB). The enhancements included the addition of height reporting events - H1 (above) and H2 (below) UE height thresholds - to help the eNB to see the UAV and to deal with any potential interference, and measures for signaling and to reduce interference by the aerial vehicles.

Release 16

Some of the key enhancements and additions of the Release 16 that can be relevant for the vertical environment include:

- Enhancements for Common API Framework for 3GPP northbound APIs (eCAPIF) that include supporting multiple API providers, CAPIF interconnection between API providers, API topology hiding, dynamically routing the service API invocations to the right end point, and registration of API provider domain functions.
- Enhancements of the URLLC mode.
- Enhancements to the 5G efficiency, including interference mitigation, SON and big data, MIMO (eMIMO), location and positioning, power consumption, Dual Connectivity (eDual), etc.
- Industrial IoT (I-IoT), including additional 5G NR capabilities such as TSN (Time Sensitive Networking) to serve in the replacement of wired Ethernet in factories.
- Integrated Access and Backhaul (IAB).
- Future Railway Mobile Communication System (FRMCS), phase 2.
- Service Enabler Architecture Layer for Verticals (SEAL), a common application enabling layer for verticals, specified in TS 23.434. To ensure efficient use and deployment of vertical applications over 3GPP systems, this specification for SEAL services includes the group management, configuration management, location management, identity management, key management, and network resource management.

Release 16 also evolves introducing, e.g., the following items:

- **New 5G spectrum, including bands above 52.6 GHz.**
- **Non-orthogonal multiple access (NOMA).**
- **NR-based access to unlicensed spectrum, including LAA (Licensed Assisted Access) and Standalone Unlicensed operation.**
- **Satellite access in 5G.**
- **V2X (Vehicle to Everything) Phase 3 including support for platooning, extended sensors, automated driving, and remote driving.**

In addition, Release 16 brings along various new Network Functions providing e.g., morenetwork enablers, trusted WLAN Interworking, and Wireline Access Gateway.

Release 16 focused on the new requirements for aerial vehicles by defining a new set of requirements in 3GPP TS 22.125 (Uncrewed Aerial System support in 3GPP), which provides “stage one” requirements for UAV support. Please note that such requirements did not lead to the introduction of any new standards features in Release 16.

Release 17

The work for aerial vehicles in Release 17, applicable to UAVs and to Urban Air Mobility, focused on:

- Enhancements to requirements for UAVs, captured in the Release 17 version of 3GPP TS 22.125 (UAS support in 3GPP).

- 5GS enhancements for the support of UAVs: this was studied in 3GPP SA2, and lead to the creation of 3GPP TR 23.754 (Study on supporting Uncrewed Aerial Systems connectivity, identification, and tracking) which documents the results of a feasibility study on supporting UAVs in 4G and 5G. The conclusions of such study were then captured in TS 23.256 (Support of Uncrewed Aerial Systems connectivity, identification, and tracking; Stage 2) which provides support of UAV connectivity for command and control (C2), support of UAV authentication and authorization, and support for enabling Network Remote Identification and Broadcast Remote Identification.

- 3GPP SA6 carried out a study in 3GPP TR 23.755 (Study on application layer support for UAS) on potential API support for UAS, focusing on UAV tracking and authorization. The results are captured in 3GPP TS 23.255 (Application layer support for Uncrewed Aerial System; Functional architecture and information flows).

- 3GPP TS 23.256 outlines further the architecture enhancements for supporting UAS connectivity, identification, and tracking, according to the use cases and service requirements defined in 3GPP TS 22.125.

- Enhancements for Common API Framework for 3GPP northbound APIs catering to API requirements for various verticals in this release, like, Application layer support for Uncrewed Aerial System, Architecture for enabling Edge Applications etc. 3GPP TS 23.255 further specifies support with CAPIF. With CAPIF support, the UAS application specific server takes the role of API Invoker as specified in 3GPP TS 23.222, consuming the UAE APIs exposed by the UAE server that is takes the role of API Exposing Function as specified in 3GPP TS 23.222.

Application Layer Support for UAS

The 3GPP TS 23.255 V17.1.0 (2021-09) is a Technical Specification of Services and System Aspects on application layer support for Uncrewed Aerial System; (UAS); it describes functional architecture and information flows (Release 17) including architectural requirements, functional model, identities, procedures and information flows, and APIs, presenting functional model for the UAS application layer. The UAS application layer functional model utilizes the SEAL services as specified in 3GPP TS 23.434.

More specifically, the 3GPP TS 23.255 presents architectural requirements for the support for communications between UAVs, QoS provisioning for C2 communication, C2 communication mode switching, support for monitoring of UAV location deviation, and support for reporting of UAV events. The UAS application enabler layer supports one or more UAS applications, whereas the UAE capabilities should be offered as APIs to the UAS application. It is organized into functional entities to describe a functional architecture which addresses the application layer support aspects for UAS applications.

Figure 1 presents a high-level principle of the architectural model for the UAS application layer, and Figure 2 depicts the architectural model for U2 connectivity between UAS UE1 and UAS UE2 at the UAS application layer. Please note that the UAS UE1 and the UAS UE2 may be a UAV Controller or a UAV.

Figure 1 Simplified UAS application layer, architectural model.

Figure 2 U2 connectivity.

The 3GPP TS 23.255 also presents relevant identities to the UAS. They are associated with the entities in the UAS application layer.

- UAV Identifier (UAV ID) is used to uniquely identify a UAV. The UAV ID is in the form of a 3GPP UE ID (e.g., GPSI, External Identifier) as specified in 3GPP TS 23.501 or CAA level UAV ID as assigned by civil aviation authorities (e.g., FAA) via USS/UTM.
- UAS Identifier (UAS ID) is used to uniquely identify a pair of UAV and UAV-C collectively known as UAS. The UAS ID is in the form of a Group ID as specified in 3GPP TS 23.434 or a collection of individual identifiers of the entities in the UAS (e.g., CAA level UAV IDs, 3GPP UE IDs).
- UAS Application Specific Server Identifier (UASS ID) is used to uniquely identify the UAS application specific server. The UASS ID is in the form of URI.
- UAE Server Identifier (UAE Server ID) is used to uniquely identify the UAE server. The UAE Server ID is in the form of URI.

Furthermore, the TS 23.255 describes the following scenarios, their information flows, procedures, and APIs:

Usage of SEAL (Service Enabler Architecture Layer for Verticals) services including Group management service, Location management service, and Network resource management service, that are applicable for consumption by UAE and UAS layer.

UAE layer registration.

Communications between UAVs within a geographical area.

UAV and UAV-C Pairing and C2 QoS Provisioning using Group ID.

Real-Time UAV Connection Status Monitoring and Location reporting.

The UAS application layer functional model enhances the simplified architectural model for the UAS application layer by specifying the functional entities at the UAS application layer. SEAL is in a key position in this; the SEAL-S reference points are specified in 3GPP TS 23.434.

3GPP TS 23.255 allows UAE server APIs for UAE capability. As per the 3GPP SA6 work group output, the following SEAL service APIs are specified in 3GPP TS 23.434 are utilized by the UAS application specific layer and UAE layer APIs:

- Group management server APIs. To UAS applications and group management for C2 communications.
- Location management server APIs. Used for UAV location deviation monitoring, UAV location reporting (trigger based, on-demand), UAVs monitoring in each location.
- Configuration management server APIs. Used to manage configurations to support UAV services
- Identity management server APIs.
- Key management server APIs. Used for key exchange for secure communication.
- Network Resource Management. Used for Event monitoring, Group based QoS management, UAS applications and C2 communications, manage unicast resources, MBMS bearer management Assisting Service continuity and Switching.

UAS application layer functional model (including SEAL and CAPIF) and details of interactions between architectural entities is described in Annex 2.

Architecture Enhancements

Related to the architectural enhancements, 3GPP TS 23.256 V17.1.0 (2021-12) is a key reference for supporting Uncrewed Aerial Systems (UAS) connectivity, identification, and tracking, according to the use cases and service requirements defined in 3GPP TS 22.125.

It specifies the following:

- **UAV tracking in the 3GPP system, including how the 3GPP system can provide support for UAV to ground identification (e.g., to authorized third parties such as police devices).**
- **UAV Identification, authentication, and authorization.**
- **Handling of unauthorized UAVs and revocation of authorization.**

An UAV is authenticated and authorized by USS via USS UAV Authentication & Authorization (UUAA) with the support of the 3GPP system before connectivity for UAS services is enabled. Depending on 3GPP network operator and/or regulatory requirements, the UUAA is performed in 5GS or EPS.

The UAS Network Function is supported by the NEF or Service Capability Exposure Function (SCEF)+NEF and used for external exposure of services to the USS. The UAS-NF makes use of existing NEF/SCEF exposure services for UAV authentication/authorization, for UAV flight authorization, for UAV-UAVC (controller) pairing authorization, and related re-authentication/re-authorization and revocation; for location reporting, presence monitoring, and obtaining list of Aerial UEs in a geographic area and control of QoS/traffic filtering for C2 communication.

Figure 3 outlines this principle.

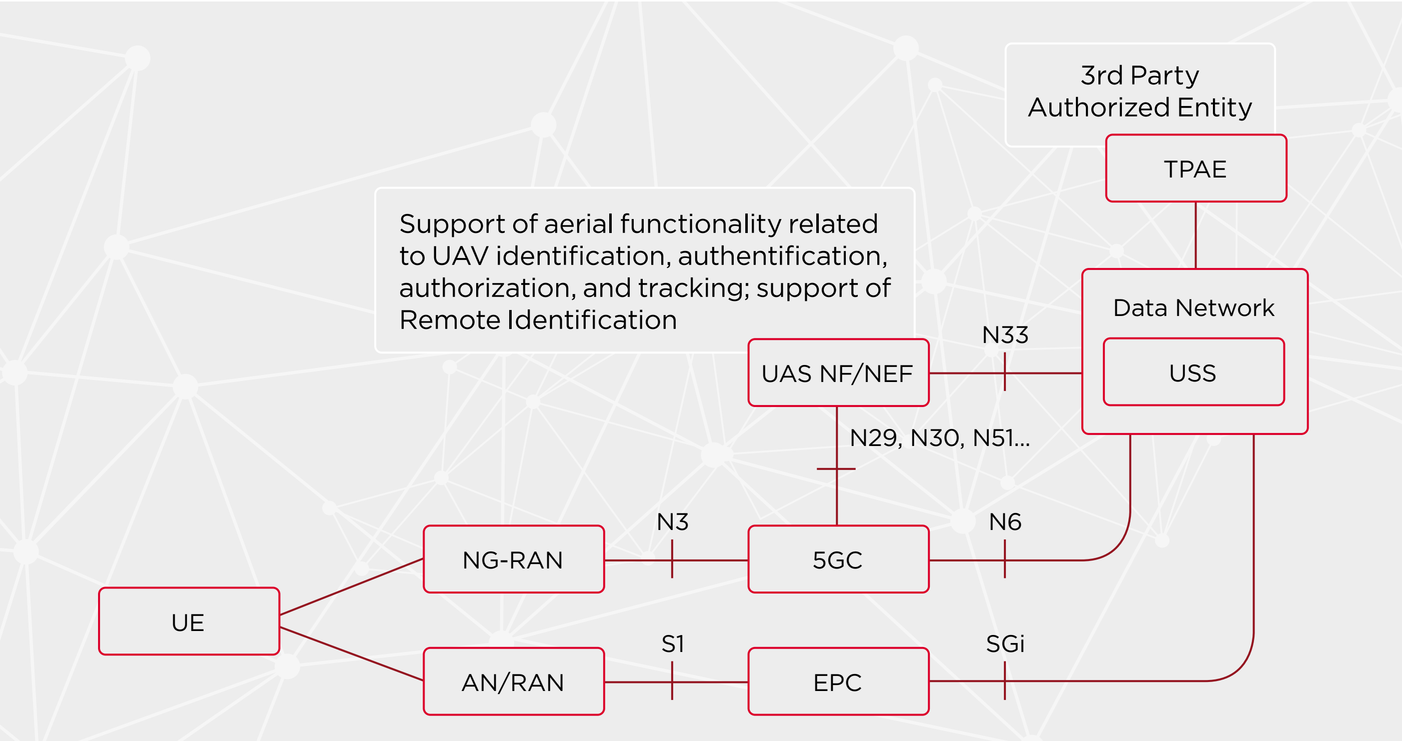


Figure 3 The role of N33 interface to serve USS. [8]

The 3GPP TS 23.256 defines identifiers relevant to UAS. These are:

CAA (Civil Aviation Authority) -Level UAV Identity. It is a UAV identity assigned by USS/UTM, and uniquely identifies a UAV at least within the scope of a USS. A UAV is assigned a CAA-level UAV Identity by functions in the aviation domain (e.g., USS). This assigned identity is used for Remote Identification and Tracking and to identify the UAV. The UAV provides the CAA-level UAV Identity to the 3GPP system during UUAA procedures. The CAA-level UAV Identity is used by the UAV as UAV identity in Remote Identification.

3GPP UAV ID. Associated to the UAV by the 3GPP system in the subscription information and is used by the 3GPP system to identify the UAV. GPSI in the format of External Identifier is used as the 3GPP UAV ID. The USS stores the association of the CAA-level UAV ID (provided by the UAV or a new one allocated by the aviation domain) to the 3GPP UAV ID (which is provided during the UUAA procedure).

Release 18 and beyond

The 3GPP continues producing Releases that focus on 5G and previous generations. The selection of the Release 18 work items is currently under work, and the latest list and news can be found at Ref. [9]

As has been already a tradition, new generation has been introduced into commercial markets each decade. 6G follows this trend as the ITU has already initiated considering new IMT-2030 requirements for the 6G, with the aim of paving the way for commercial phase of 6G in 2030s.

While the concrete requirement statements of the ITU are still under work, and the standards setting organizations are preparing to start forming their specifications upon the possibilities later, information about the of 6G can be found at Ref. [10].

As an example, the 6G architectural aspects are presented in Network 2030 Architecture Framework Technical Specification at Ref. [11]

Other Initiatives

Aerial Connectivity Joint Activity (ACJA)

The **ACJA** is a joint activity between GSMA and the Global UTM Association (GUTMA). The purpose of the ACJA is to encourage cooperation between wireless cellular interests and aviation interests, especially for promoting common understanding and eventual industry standardization of capabilities to benefit small UAS. See Ref. [12] for more information about the scope and activities of the ACJA.

The ACJA has divided itself into four (4) work tasks:

Cellular Standards Coordination (3GPP): provide information to 3GPP to assist with wireless communications needed for UAS.	**Standard Aerial Service Profile (published LTE Aerial Service Profile, see below).**
Interface for the Data Exchange between MNOs and the UTM ecosystem (published Network Coverage Service Description, see below).	**Supporting development of Minimum Operational Performance Specifications (MOPS) and Minimum Aviation System Performance Standards (MASPS): document cellular network performance in aviation terms.**

Significant (and publicly available) publications to date in ACJA include the following:

The LTE Aerial Profile document identifies a minimum mandatory set of features which are defined in 3GPP specifications. Aerial wireless devices within a drone and supporting networks are required to implement these features to guarantee an interoperable, LTE aerial service over Long Term Evolution (LTE) radio access. [1]

Leveraging 3GPP Cellular Network Mechanisms to Support UAS Operations focuses on analyzing how cellular networks and related services can be leveraged to support UAS operations , including how they support ASTM 3411-19 Standard Specification for Remote ID and Tracking and future versions. [40]

ACJA Interface for Data Exchange between MNOs and the UTM Ecosystem: Network Coverage Service Definition v2.00 was published by Aerial Connectivity Joint Activity in January 2023. It describes the Network Coverage Service, a general architecture comprising stakeholders, services, interfaces, and data models for the automated data exchange between MNOs and the UTM ecosystem. [41]

Reference Method for assessing Cellular C2 Link Performance and RF Environment Characterization for UAS was published by ACJA in Oct. 2022. This paper provides a method comprising of a minimum set of descriptions to standardize the way that C2 link performance and RF measurements are to be conducted for the characterization of the connectivity in the airspace. [42]

Landscape whitepaper on UAS Cellular Ecosystem was published by ACJA in February 2023. This whitepaper is intended to describe an exhaustive set of entities involved in cellular communication of uncrewed aviation systems, their interrelationship between each other, ACJA activities, and external standardization activities. [43]

ATIS UAV

In 2017, ATIS launched its Uncrewed Aerial Vehicle (UAV) initiative to apply ATIS members' expertise in mobile cellular and other communications networking technologies to better understanding the interaction of UAVs and communication technologies. A focus of the UAV group is to advance the use of mobile cellular networks (especially 3GPP specified technology) to support the communication needs of UAVs. This includes monitoring and advancing the development of 3GPP specifications to address UAV-related requirements. The group helps align member strategies and contributions in 3GPP including gaining support for new 3GPP UAV-related work items.

ATIS has published the following reports developed by ATIS UAV:

- **Use of Cellular Communications to Support Unmanned Aerial Vehicle (UAV) Flight Operations (August 2019). [15]**
- **Use of UAVs for Restoring Communications in Emergency Situations (December 2018). [16]**
- **Support for UAV Communications in 3GPP Cellular Standards (October 2018). [17]**
- **Unmanned Aerial Vehicle Utilization of Cellular Services (September 2017). [18]**
- **3GPP Release 17 – Building Blocks for UAV Applications, ATIS-I-0000092 (July 2022). [19]**

ASTM

The ASTM F38 committee develops standards that support many facets of small UAS. ASTM F3411 (Standard Specification for Remote ID and Tracking) was published in Feb. 2020 and supports the use of both Bluetooth and Wi-Fi for a drone broadcast remote identification capability. The standard also supports network remote identification, i.e., publishing the drone remote ID to a network so that UTM and USS systems can provide a set of services to these networked drones. The standard was developed based on the original FAA NPRM on UAS remote identification which included requirements for both network and broadcast remote ID.

However, in Dec. 2020, the FAA final rule on remote ID was published, and network remote ID was no longer required. Only broadcast remote ID was required in the final rule, citing examples of Bluetooth and Wi-Fi as technology choices for broadcast. The remote ID standard was revised to support the requirements in the FAA final rule and was published in July 2022 as F3411-22a (Standard Specification for Remote ID and Tracking).

ASTM also published an associated Means of Compliance (MOC) in July 2022 to assist drone manufacturers with satisfying FAA regulations in ASTM F3586-22 (Standard Practice for Remote ID Means of Compliance to Federal Aviation Administration Regulation 14 CFR Part 89).

It is interesting to note that direct cellular broadcast technology was not ruled out; however, there are currently no 3GPP standards to support direct cellular broadcast from drones to support remote ID. This capability is currently being worked in 3GPP Release 18 and could eventually be added to the ASTM remote ID standard in the future.

In 2021, ASTM published F3548-21 (Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability) and began work on a new Specification for Positioning Assurance, Navigation, and Time Synchronization for Uncrewed Aircraft Systems.

GSMA

GSMA published the first version of the LTE Aerial Profile in November 2021 in the Permanent Reference Document (PRD) NG.128. It identifies a minimum mandatory set of features defined in 3GPP specifications which an aerial User Equipment and network are required to implement to guarantee an interoperable LTE aerial service over LTE radio access.

The primary use case of this profile is UAS, but it also can be used for other commercial applications in low altitude airspace.

The identified parameters and functions are based on the assessment of the 3GPP which is documented in the TR 36.777. [20]

The NG.128 defines a profile for LTE Aerial Service by listing a few LTE, EPC, and UE features that are considered essential to launch interoperable services. The defined profile is compliant with 3GPP specifications. The scope of this profile is the interface between UE and network, where the UE is an aerial user equipment. [1]

The profile does not limit deployment of other standardized features or optional features, in addition to the defined profile.

GSMA Foundry

GSMA Foundry provides a fora for cross-industry collaboration and business development, where GSMA members and industry players come together to rapidly develop real-world solutions to industry challenges, nurture new ideas through initial commercial trials, and scale proven solutions at a regional and global level to forge digital future. (Ref: https://www.gsma.com/foundry/)

The GSMA Foundry is comprised of various projects with the principle to explore the selected topics in a short timeframe.

Of the past and ongoing projects related to NAVA perspectives, these two examples are the most relevant ones:

- **5G – Enabling Enterprise Drones to fly BVLOS. The aim of the project is to help the drone ecosystem and global stakeholders to develop common guidelines and for regulators to consider similar rules.**
- **5G Autonomous Drones. The project showcases the use of 5G drones both indoors and outdoors, and demonstrates the benefits of 5G, such as low latency communication across fleets of drones and high bandwidth data transfers in the form of real-time video and AI/analytics.**

GSMA also maintains a 5G Transformation Hub, which is a portal for presenting innovative 5G case studies that demonstrate the value of 5G solutions for a range of industries. Related to the case studies visible on the Hub, there is also a GSMA 5G Industry Challenge that calls for 5G case studies for mobile innovation and 5G industry challenge awards.

This activity is to encourage participants to provide information that has demonstrable value of 5G and the growth in 5G global adoption.

An example about the topics mapping with NAVA efforts that the Hub presents are indoor and outdoor drone use cases, as well as a project that demonstrates how 5G drones help deliver digital twins. (Ref: https://www.gsma.com/5ghub/)

GSMA Drone Interest Group

The GSMA's membership-based Drone Interest Group (DIG) investigates and assesses the opportunity for mobile connectivity to be deployed in commercial UAVs and the applicability of SIM to identify them. DIG has produced 14 publications since 2017 as listed in [44].

The most recent publication focuses on the potential business models for the MNOs and it covers 18 use cases [45].

The participants represent mobile operators and GSMA associate members working with UAS and UTM suppliers and other ecosystem stakeholders to encourage the use of cellular communications for drones.

The group shares industry knowledge and position mobile operators as key enablers for the autonomous BVLOS growth.

The goal of the DIG is to better understand the drone sector, increase awareness of respective regulatory and technical challenges, and discuss ways to address these topics. (https://www.gsma.com/iot/drones-interest-group-dig/)

Open Generation

The MITRE Engenuity Open Generation 5G Consortium is a privately funded research and development (R&D) community launched by MITRE Engenuity in 2020. It brings together multiple industry sectors, academic institutions, industry associations, along with government perspective, with the mission to perform use-case driven R&D that utilizes 5G and beyond capabilities, to achieve breakthrough innovation in the U.S. and democratic societies.

The first use cases selected by Open Generation focus on UAS, in particular those intended to operate BVLOS, that benefit the most from wide-area cellular network architectures .

Experimental efforts are under way as part of the Open Generation collaboration, including the recent deployment of a private 5G network at Northeast UAS Airspace Integration Research Alliance, Inc. (NUAIR) test site located in Rome, NY, which effectively enables UAS tests over 5G at an FAA-designated UAS test site, under BVLOS conditions. Additional ongoing Open Generation efforts on UAS 5G experimentation include the implementation of an outdoors private testbed supporting mmWave at Virginia Tech facilities in Blacksburg VA, and an indoor test site at Northeastern University in Burlington, MA.

See Mitre Engenuity Open Generation information on 5G advantages for connected UAVs (including Detect and Avoid procedures using 5G technology) here. [50]

Use case assessment

Open Generation UAS Use Cases

Four priority use cases were initially selected for **research and development by the Open Generation consortium**, with operational requirements that represent a wide range of possible UAS applications. Those four use cases are briefly described below. Additionally, the Open Generation consortium is currently developing a use case description for Urban Air Mobility (UAM)/Advanced Air Mobility (AAM), here. [50]

Emergency Response

Within the broad category of Emergency Response, there are several specific use cases, for example, drone as a first responder, damage assessment, hazmat incident response, lost person search. A common thread for these use-cases is the need to provide high-quality visual as well as other types of sensor data to incident responders. Given the fluid situation as incidents unfold, and due to the unstructured environment, the drone needs to operate in, there is a need for manual piloting of the drones to maneuver the drone into proper positions. Multiple drones may be in use concurrently at an incident as well as other manned aircraft, such as helicopters, may be operating at a low altitude in the area. Sophisticated detect-and-avoid (DAA) solutions need to be in place for these operations.

Static Infrastructure Inspection

There are 60,000 distribution substations in the United States energy grid. Efficient maintenance of a large and often remote set of stations is a key industry challenge. Drone-in-a-box solutions provide potential remedies for costly inspections. For this use case we have a limited geographical area, where drone inspection flights take place. The delimited operation area provides opportunities to relax some operational requirements as well as allows for a local 5G network to support operations.

Package Delivery

There is high interest in using UAS to increase product distribution, reduce product delivery times and achieve corresponding potential cost savings. This use-case is focusing on the last delivery segment of a package to its final destination from a distribution center. We assume that the delivery drones are stationed at a warehouse infrastructure that allows loading/unloading of packages, and take-off and landing of multiple drones. The warehouse and its immediate proximity is covered by a private 5G network while the actual delivery segment of the flight is supported by a public 5G network. Flight operations are automated including DAA mechanisms. Deliveries can be in urban, suburban, and rural areas each of which is presenting unique challenges for the UAS operation as well as for the communication technology.

Indoor Inspection

Drones are used indoors to fly programmatically defined missions within warehouses and other large indoor spaces, to collect images and/or stream video for indoor inspections, warehouse inventory management, or indoor security. The communication is supported by an indoor private 5G network. Given the indoor operation, typical airspace regulations are not applicable. However, worker safety is a key concern and mechanisms need to be in place to prevent injuries and equipment damage. When people and drones are working in the same space, connecting other safety systems to the 5G network, for example, emergency shutoff buttons scattered on the warehouse floor will be likely required for worker safety.

Agricultural use cases

Uncrewed aerial vehicles can be of help in an increasingly large number of environments. Among many other, agriculture represents a vertical that can benefit from robotics and accompanying drones to, e.g., optimize harvesting of crops. Connected to intelligent sensors and predictive systems considering weather conditions, markets, and other attributes, the outcome includes cost and environmental savings and better targeted markets to minimize the waste of product.

As an example, Georgia Institute of Technology (Georgia Tech) and the University of Arkansas have been investigating autonomous robotic system that aims to complete previously largely manual tasks such as berry picking. In this study, an autonomous robot could perform much of the delicate operation by using a special robotic gripper without damaging the plant or the berries. [21]

Such an environment could benefit further from cellular-connected drones contributing to monitoring of the harvesting areas, to pinpoint the priority locations, and to help in surveillance of forest fires.

Urban/Advanced Air Mobility

Much global work is emerging around the concept of Urban & Advanced Air Mobility (UAM/AAM). As of the writing of this paper, these concepts have fluid definitions and are nascent in maturity. Urban Air Mobility (UAM) traditionally referred to the transport of passengers via eVTOL UAS over dense urban metropolises.

Advanced Air Mobility (AAM) is growing in adoption to include larger airframe eVTOL UAS for the purpose of cargo delivery, as well as scaled package delivery.

Cellular mobile networks roles in the support of UAM & AAM will undoubtedly look different than the support for sUAS, which is the primary focus of this paper, due to the larger airframe and complex operational model to perform missions such as delivering passengers over a city or large cargo payloads over a rural terrain. In addition to supporting functions discussed already, such as basic C2, telemetry, and payload data, mobile networks will play a larger role in the support of vertiport operations, deconfliction, detect and avoid, and potentially more. Though this topic will not be discussed further here, for the interested and unfamiliar reader, resources are provided for further exploration.

Please refer to [46], [47], [48], and [49] for more details on the related GSMA Smart Mobility, Boeing Urban Air Mobility concept of operations, FAA UAM concept for operations, and NASA AAM campaign, respectively.

Third Party Service Providers

The objective of the GSMA NAVA is to assist with implementation and facilitate market factors for vertical ecosystem vendors. Topics of regulatory activities, supporting technology for key UAS operational needs, and **roles in supporting the UAS ecosystem are important for the 3GPP ecosystem to understand**.

Regulatory Activities: FAA BVLOS ARC

As of this writing, the FAA has yet to establish a clear regulatory framework for UAS BVLOS operations. This is seen as the largest barrier to scale of the UAS ecosystem in the US. In June 2021, the FAA set forth a charter to establish an Uncrewed Aircraft Systems (UAS) Beyond Visual Line-of-Sight (BVLOS) Operations Aviation Rulemaking Committee (ARC). The UAS BVLOS ARC provides recommendations to the FAA for performance-based regulatory requirements to normalize safe, scalable, economically viable, and environmentally advantageous UAS BVLOS operations that are not under positive air traffic control (ATC). [22]

The ARC's recommendations addressed requirements to support four (4) high value commercial use cases: long-line linear infrastructure inspections, industrial aerial data gathering, small package delivery, and precision agriculture operations.

The ARC activity sets forth the regulatory foundation for sUAS rulemaking and may set precedence for larger aircraft operations such as Advanced Air Mobility (AAM). The ARC process was completed in March 2022, and the final ARC report can be seen here. At this time, the ARC deliverable is being reviewed by the FAA and the process of official rulemaking will begin. This process has historically taken 6-18 months to complete for previous drone rulemaking committees, Remote ID & LAANC.

Associated Elements

The FAA introduced the concept of Associated Elements in July 2021 via a memo which defines a UAS as a UA and its associated elements (AE), including communication links and the components that control the UA, that are required to operate the UAS safely and efficiently in the national airspace system. [23] The AEs discussed in the memo are those elements which are not airborne or directly affixed to the aircraft and the boundaries between Type Certification of an aircraft and FAA Operational Approval are discussed.

This include the 3GPP Mobile Network supporting UAS including but not limited to the usage described in the ACJA LTE Aerial Profile v1.0, Section 2: LTE Aerial Data Types, and is generally accepted as a necessary step towards the ability to scale 3GPP systems to support UAS operations. [1]

Please note that not all UAS will require Type Certification. The decision to pursue Type Certification is dependent on the purpose and operational aspirations of the aircraft.

FAA Operational Approval

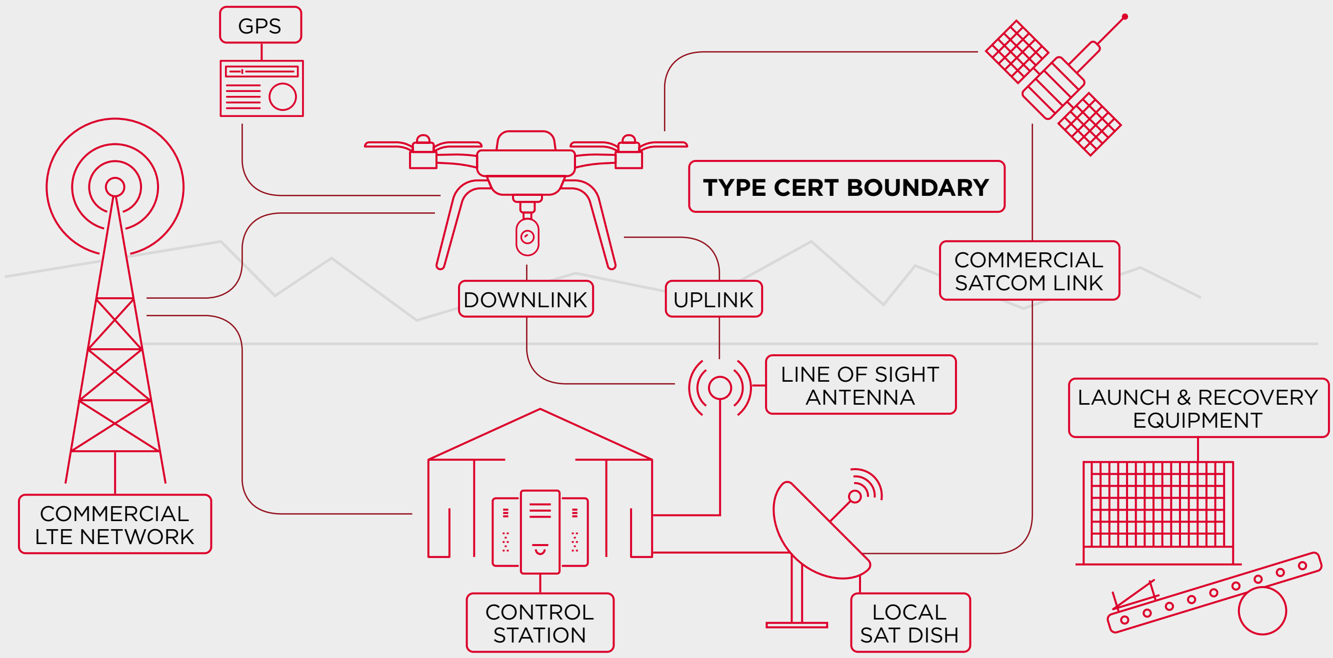


Figure 4 UAS Approval Boundary: Supporting Technology for Key UAS Operational Needs.

3rd Party Services

A Third Party Service Provider (3PSP) is an Associated Element or Supplemental Data Service Provider for assisting UAS Operators. This could include command and control links, ground based Detect and Avoid (DAA) services, or other services such as launch and recovery automation, remote pilot stations, or dispatch automation of a mixed fleet of Uncrewed Aircraft. Third Party Service Providers may exist within or outside of a notional UTM system.

A **Supplementary Data Service Supplier (SDSP)** is defined as a 3rd Party Service Provider (3PSP) which provides operational data to the USS &/or operator.

A **C2 Communications Services Provider (C2CSP)** provides connectivity between the control station and the UAV. According to RTCA DO-377 A.2.9.1, the goal of a C2CSP is to provide portions of the connectivity between the Ground Control Station (GCS) and UAV in a cost-effective and safe system that can be approved by the FAA as part of a UAS certification. These services will likely require some level of Service Level Agreement & Means of Compliance. A C2CSP can utilize the services of multiple connectivity providers.

A **Service Level Agreement (SLA)** refers to the agreement between the 3rd Party Service Provider (3PSP) and the UAS operator covering the safety, performance, service area, and security of the third-party UAS Service being provided to the UAS operator.

Means of Compliance (MOC) refers to a detailed design standard that, if met, accomplishes the safety intent of the regulation, is used to show compliance with regulations, and accepted by the Administrator.

While MNOs are a stakeholder in the C2CSP concept, it is not required that an MNO be a C2CSP or a USS; however, these concepts provide value to the 3GPP ecosystem to demonstrate the types of services which support UAV operations.

Supplemental Data Services to Support UAS

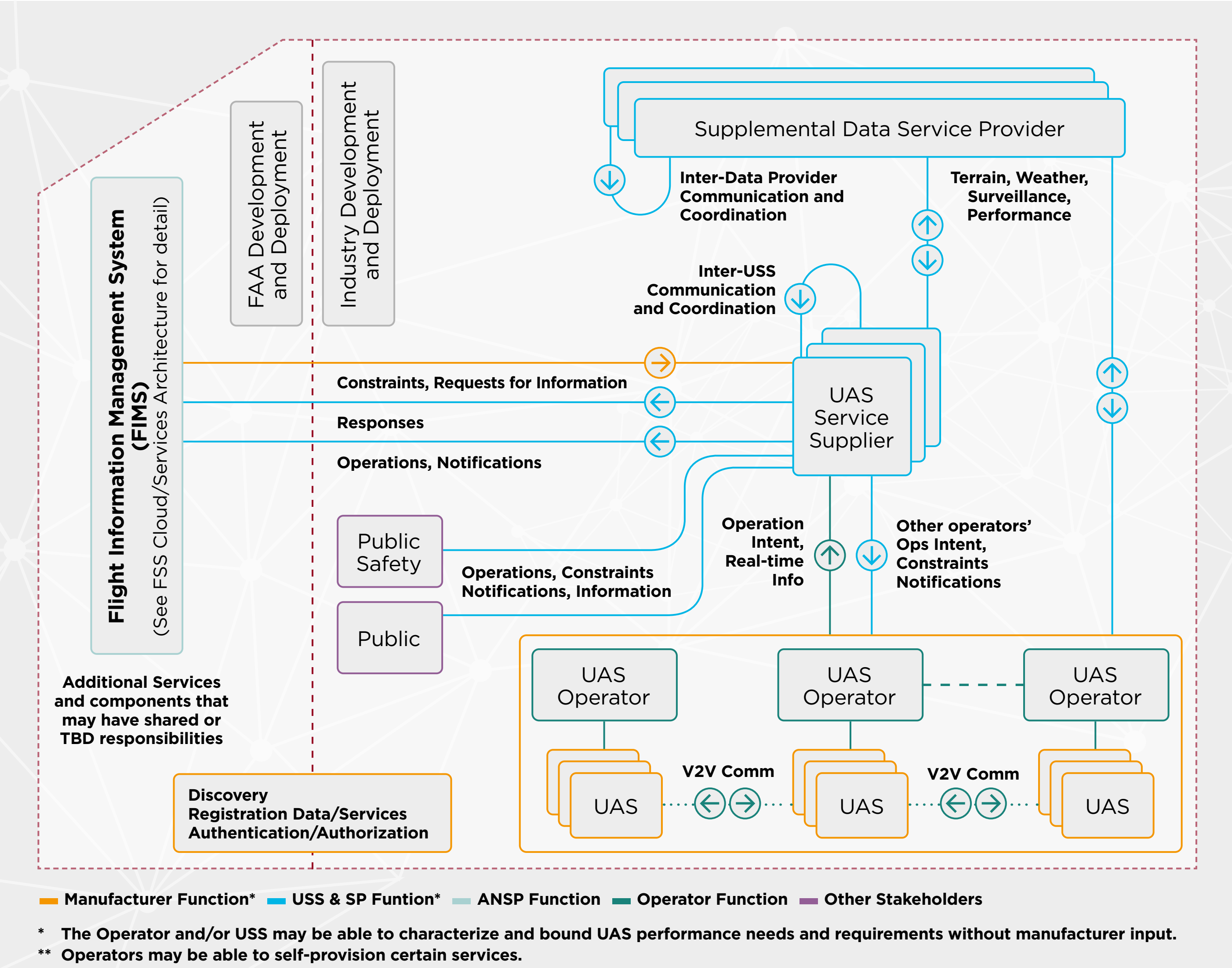


Figure 5 Notional UTM Architecture

As depicted in Figure 5 on the FAA Notional UTM Architecture (v2), an MNO can act in multiple roles and correspondingly provide multiple types of operational data and services. Today, MNOs offer services which can be incorporated into a UAS operation and loosely fit the definition of SDSP service such as location-based services and severe weather alerts. While these services present an opportunity for a MNO to leverage services above and beyond data transport, it is not assumed that an MNO must take on the role of an SDSP within a UTM system to support UAS operations.

Trends in standards organization and global regulations indicate that MNOs who wish to leverage their networks for the purpose of supporting C2 for UAS at scale may be required to provide services beyond connectivity only. This is generally not available in the market today. These additional services can be delivered by an MNO or its affiliate serving in different roles:

Connectivity Provider,

Supplemental Data Service Provider, and

Command and Control Communications Service Provider (C2CSP)

Potential Roles of MNO in Support of Drone Operations

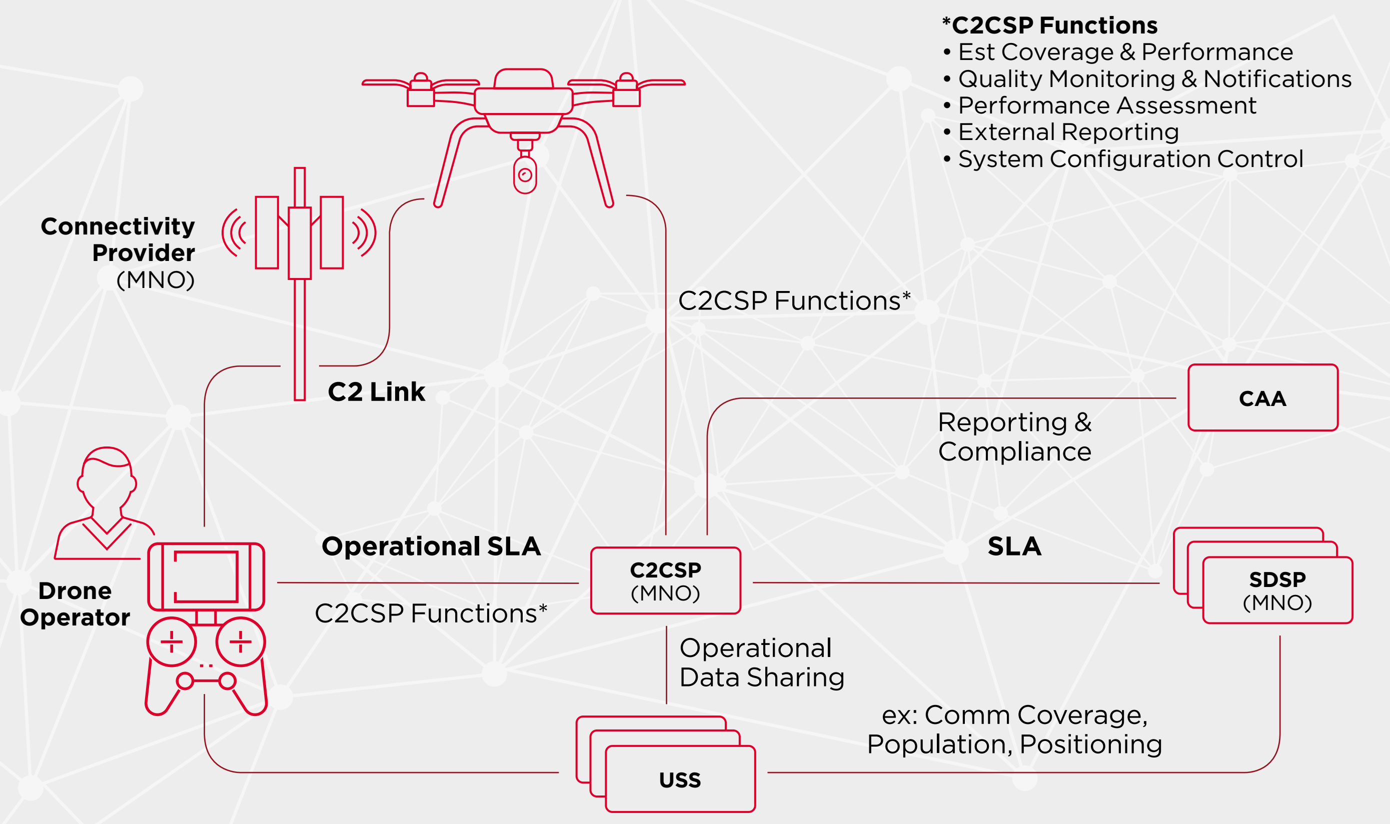


Figure 6: Potential Roles of a MNO in Drone Operations

Figure 6 depicts a notional drone operational landscape with the 3 potential roles of an MNO shown in the boxes with "(MNO)".

Here, the connectivity provider is assumed to be solely a 3GPP MNO. A UAS may utilize multiple connectivity providers including non-3GPP systems. The concepts here are translatable to other communications connectivity types, such as satellite and terrestrial point-to-point radio networks. A C2CSP, in this case, would need technical and business arrangements with each connectivity provider.

The three MNO roles are discussed below:

1. **Connectivity Only:** In this role, a MNO provides commodity connectivity between a drone and its control station. MNO is not providing any substantive value-added services to assist the drone operator. This is the state of many MNO services today. Currently, some MNOs have specific data plans and restrictions for aerial UEs, but others do not. If an MNO offers additional services beyond connectivity, they likely will need to identify and manage aerial devices on their network different from terrestrial UEs.

2. **SDSP:** In this role, a MNO is providing risk-reducing and informational services supporting the planning, execution, and evaluation of UAS operations. As shown in the above figure, the MNO may provide a host of network-derived information including communications coverage, ground population, augmented positioning, and tracking and identification services. These services can be provided to a USS within a UTM system or could be provided to a C2CSP regardless of the existence of a UTM system.

Likely, the MNO would need to have a closer relationship between the UAS, its operator, and its own network than what typically exists today. As an example of SDSP communications services, see the ACJA Interface for Data Exchange between MNOs and the UTM Ecosystem: Network Coverage Service Definition v1.00. [14]

3. **C2CSP:** In this role, a MNO is providing C2 services according to the requirements of a Civil Aviation Authority, such as the FAA. This C2CSP sits above the commodity MNO connectivity service and manages C2 communications services with a drone operator. The figure summarizes some of those functions. A C2CSP can exist regardless of the existence of a UTM system. In order to deliver C2 services, the C2CSP will need relationships between drone, control station, drone operator, MNO (acting both as a Connectivity Provider and SDSP), the CAA, and possibly to the UTM system. A more detailed description of the relationship links follows:

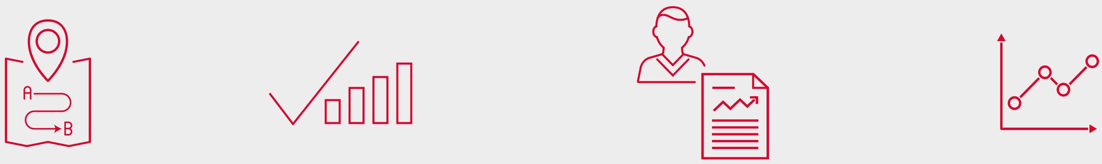
    a. **C2CSP to Drone and Control Station:** The C2CSP provides all required C2CSP function and is aware of the operating state and performance of the UAS UEs during the execution of a drone operation to deliver the required services.

    b. **C2CSP to Drone Operator:** The C2CSP and Drone Operator have an Operational SLA that is satisfactory to the CAA's regulatory requirements.

    c. **C2CSP to SDSP & Connectivity Provider (link not shown):** The C2CSP and SDSP / Connectivity Provider have a lower level SLA that supports the delivery of the Operational SLA. This is a lower-level agreement between commercial entities. Data provided by the SDSP & Connectivity Provider enables the delivery of C2CSP services, such as in-flight performance monitoring.

These MNO roles are not mutually exclusive. An MNO may serve in many different roles at the same time depending upon the nature of a customer's operational need, the maturity of a UTM system, and specifics of an SLA. These roles are inclusive of services provided by an MNO to provide strategic (pre-flight) and technical (in-flight) air and ground risk mitigations, and post-flight compliance reporting.

Figure 7 Example workflow for coverage planning in a 3GPP system



Plan:

- Operator gets request for mission
- Chooses flight plan/path based on mission need > waypoints are generated
- Waypoints are compared against coverage

Approval:

- Coverage is verified
- Network notifications are issued directly
- Mission is approved

Execution:

- Coverage data is logged via onboard software while inflight
- Network conditions are monitored while flight in progress, notifications sent to operator

Analysis:

- Coverage and Aircraft data is analyzed for compliance (via SLAs)
- Data is stored and cached
- Data may be shared with regulatory agencies

Figure 7 demonstrates how these roles are integrated into a single workflow using coverage planning as an example. Since 3GPP systems are not ubiquitous in coverage, the ability of an MNO to provide coverage and performance estimations for the purpose of flight path planning is considered a need to support C2 of a UAS. These services may also provide value to users of the 3GPP systems for the support of data transport services not related to the command and control of the aircraft such as HD payload imagery and video streaming.

These uses of the communications link place high operational value on quality link services, especially those where the mission requires situational awareness or near-real time data insights such as map generation or live video stream and distribution.

Table 1 provides a high-level summary of the types of roles an MNO may assume given current drone regulatory & standards trends, and the Supplementary Data Types associated with each role. Notionally, an MNO may start as a “Connectivity Provider” and progress towards a “C2CSP”. As an MNO makes these advances, there is an increase in the value of the services offered at the cost of increased operator-drone OEM and MNO technical complexity.

Role of MNO, as a:	Provided Data	Interfaces	Provided Services
Connectivity Provider	UE Data, SCEF/NEF	cellular modem, Business as Usual (BAU)	data transport
SDSP (for an USS)	coverage, population, positioning	SDSP <> USS	coverage, ground risk
USS (hosted by MNO)		UAS, UAS Operator, FAA, other USS	all or selection of typical USS services
C2CSP inside of a UTM system		UAS, connectivity providers, other networks, USS,	pre-flight estimate, in-flight monitoring, post-flight assessment & reporting, inter-USS sharing
C2CSP outside of a UTM system		UAS, UAS Operators, connectivity providers, other networks, USS,	pre-flight estimate, in-flight monitoring, post-flight assessment & reporting

Table 1 Roles of MNO in the UAS ecosystem and associated Supplementary Data Types.

Note on Airspace Coordination & Mitigating Air Risk: Vehicle to Everything (V2X)

3GPP TS 23.255 (Rel 17) [24], states support for the communication between the UAV & ground station (UAV-C) over Uu interface as an architectural requirement. This direct communication between vehicles is referred to as V2X (in this case, V2V) and provides communications between UAVs in a geographical area using unicast.

A critical component to enabling complex, high ROI applications is through BVLOS and 1:M operations; this requires safe, fully autonomous operations at scale. For BVLOS flight, both the connection between drone and operator and the drone's ability to operate autonomously become crucial. In traditional aviation, some of this is done by the pilot. In uncrewed aircraft, the nature of satisfying DAA and deconfliction changes, and places more value on the capabilities of the drone system.

The airspace also requires coordination, and therefore the drone system being connected to a network is a key enabler of drone autonomy. In contrast to the traditional air traffic control system today, the notional UTM system is intended to be a highly digital system.

This orchestration of autonomous aerial vehicles in a digitally coordinated airspace will require secure communication and messaging between various UEs (vehicles & controllers). Parallel use cases may be cited from the autonomous vehicle industry which has begun to define communication and messaging needs required for critical autonomous machine orchestration.

The implementation of products and services in North America which support UAS should be considered from the perspective of the transportation vertical today, in which V2X communications is one of the enablers that can be employed to improve traffic safety and efficiency. [25] To support ecosystem and industry scale, technology which supports autonomous vehicles should be referenced and implemented when appropriate for the UAS application. This includes requirements for Global Interoperability.

Drones are a global business. In the effort of promoting cellular as a leading technology for adoption, UAV manufacturers & ecosystem system providers must have assurance that a single vehicle can be implemented in multiple geographic locations and maintain a basic level of operation.

For cellular ecosystem vendors, first order minimum requirements to support this goal for 4G LTE systems are described in the Aerial Service Profile.

Other Relevant Terminology Definitions

Uncrewed Aircraft System Service Supplier (USS).
A USS is a person (as defined by 14 CFR 1.1) qualified by the Administrator to provide Associated Element or Supplemental Data provided as a service to uncrewed aircraft systems.

Detect and Avoid (DAA)
The capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action to comply with the applicable rules of flight. [26]

UAS Traffic Management (UTM).
A set of automated functions and digital services designed to support safe, efficient, and secure access to airspace for UAS. These services include network remote identification; UAS flight authorization; geo-awareness and traffic information; and any other services as defined by the Administrator.

Strategic Mitigation.
Mitigation strategies designed to reduce the effects of hazards prior to flight (e.g., operations restricted from being conducted over densely populated areas) (See also Technical Mitigation)

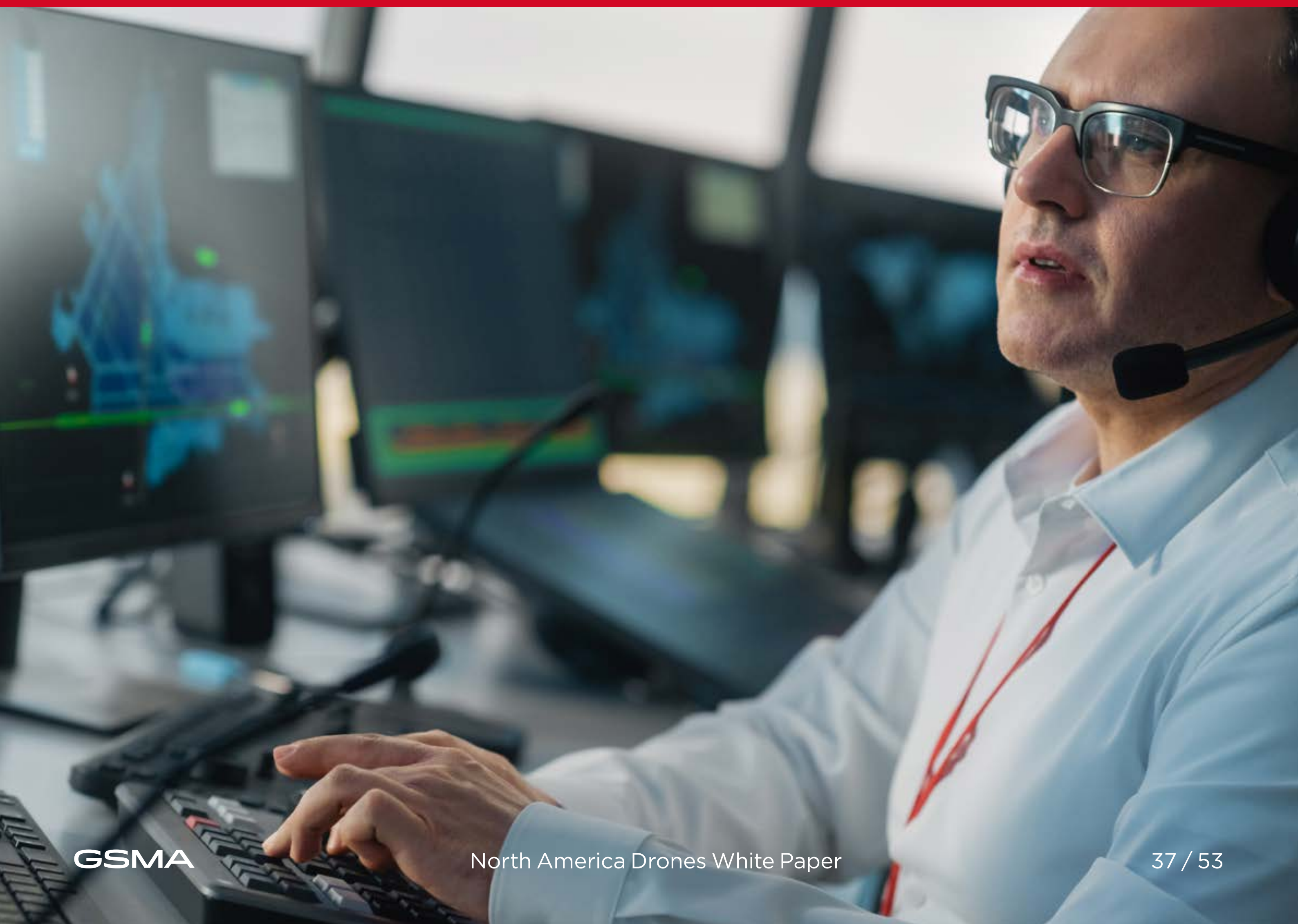
Service level agreement (SLA).
The agreement between the 3PSP and the UAS operator covering the safety, performance, service area and security of the 3rd Party UAS Service provision as required for the UAS operator's intended operations.

Technical Mitigation.
Mitigation strategies designed to reduce the effects of hazards associated with technical system states such as software and hardware. Strategic mitigations reduce risk prior to flight, while technical mitigations reduce risk inflight.

Remote ID

UAS remote identification provides a capability for a drone to provide information about itself and its controller to persons or organizations with an interest.

Interested parties include civil aviation authorities controlling the National Airspace (NAS), members of law enforcement, and members of the public who may want to understand more about drones flying in their area.



The FAA has defined remote identification as a required broadcast capability for UAS in their final rule published in Dec. 2020. There are three basic categories of UAS with respect to remote ID:

- Standard Remote Identification Uncrewed Aircraft: this is related to identification via message exchanges in broadcast, to include the UAV serial number, its position, and performance data.
- Remote Identification Broadcast Modules: this is similar to the previous one but uses a separate broadcast module. This option seems to lend itself better for retrofit of vehicles that were built without standard remote identification built into the UAV itself.
- Uncrewed Aircraft without Remote Identification Equipment: this allows the operation of UAVs without any identification but under very strict conditions, mainly strict visual line of sight and in FAA-recognized Identified Areas (FRIAs).

Note that the ASTM F3411-22 standard for Remote Identification was published in July 2022 and supports the FAA-required identities for direct broadcast from the UAV using Bluetooth 4/5, Wi-Fi NAN, or Wi-Fi beacon technologies. The ASTM Remote ID standard also supports network remote ID (which is not required by FAA rule). On Aug. 11, 2022, the FAA released Federal Register :: Accepted Means of Compliance; Remote Identification of Unmanned Aircraft. This is a clear indication that the FAA has formally embraced the published MOC in ASTM F3586-22 based on the revised remote ID standard ASTM F3411-22. [27]

Network RID aspects (e.g., beyond Broadcast RID)

Network remote ID will be useful for the support of allowing network-based services to be provided to drones, i.e., by UTM and UAS Service Suppliers (USS). Note that while the FAA removed the network remote ID requirement from its final rule for remote ID, the FAA has indicated that network remote ID (as a supplement to a broadcast-based solution) is not disallowed by the regulations, and thus, the industry may pursue network remote ID solutions outside the scope of formal regulations.

Security requirements/considerations

The ASTM broadcast remote ID solution provides hooks for security support, but there is no formal security mechanism required by the FAA rule on remote ID. For example, IEEE 1609. 2 already supports a certificate-based standards approach for local authentication that could be used for securing broadcast remote ID. This approach has already been used to secure Cellular Vehicle-to-Everything (C-V2X) communications.

Conclusions

This whitepaper presents technical background of cellular-connected UAVs and discusses the needs for ensuring fluent development of the related ecosystem in North America and wider areas.

Cellular-connected UAVs and their supporting communications infrastructure are developing firmly as can be seen in the efforts of 3GPP and other industry activities. Many use cases that are already in place or will become reality soon, indicate the need for the further development of the ecosystem.

Cellular networks suit well to serve UAS communication needs for both payload as well as C2. Nevertheless, there are still items that require further development. One of such topics is the network-based Remote ID. The ongoing 3GPP R18 work to support Broadcast Remote ID via PC5 direct communication (similar to technology used for C-V2X) should provide a cellular capability to operate alongside the existing Wi-Fi and Bluetooth methods for Broadcast Remote ID in the ASTM Remote ID standard.

The standardization of features related to UAVs has advanced firmly. The 3GPP Release 15 presents many definitions for 4G as well as 5G, including aerial vehicles authorization and interference reduction in LTE networks, and 5G network functions that UAVs can benefit from in the service-based architecture.

The enhancements of the Common API Framework for 3GPP Northbound APIs (eCAPIF) is one example of a facilitator in Release 16, and Service Enabler Architecture Layer for Verticals (SEAL) is yet another. The Releases 17 and 18 further complement and enhance the set of features to support UAVs benefiting connectivity, identification, and tracking.

Of the other initiatives, one of the most relevant ones is the Aerial Connectivity Joint Activity (ACJA) together with GSMA that has produced the LTE Aerial Profile (GSMA PRD NG.128) based on the 3GPP Release 15 key features. Other important sources and entities include several reports of the ATIS UAV initiative, standards development of ASTM F38, and the field and lab testing of ecosystem.

Regarding practical testing, Open Generation, funded by MITRE Engenuity, has published their use case studies on emergency response, package delivery, static infrastructure inspection, and indoor inspection. These experiments serve as a foundational information source to better understand the current performance and need for further development of cellular-connected drones.

The core of this whitepaper is discussion on how the vertical ecosystem could best implement and facilitate market factors for vendors.

Regulation is in a key role to facilitate regional and global market development through the technical enablers. Of the regulation in the North America region, the FAA BVLOS ARC is a foundational activity for UAS rulemaking. This whitepaper presents the essential summary of its contents and discusses further need for evaluating the possibilities to include the network-based Remote ID in the regional set of opportunities.

This whitepaper discusses further the remote ID aspects and issues. Network-based Remote ID is in fact considered as useful for the support of allowing network-based services to be provided to drones. Some of the benefiting entities are UTM and UAS Service Suppliers.

Even though the FAA has not included the Network-based Remote ID requirements at present, it is worth noting that the regulation does not prohibit it either; thus, the industry may pursue Network remote ID solutions outside the scope of formal regulations.

In closing, it is encouraged that the information presented be used to further ideate, collaborate, and innovate with ecosystem partners to expand commercial adoption and regulatory advancement of cellular networks as a viable economic solution to support the safe integration of UAS in the National Airspace System (NAS) for more complex missions.

UAS airframe & communications equipment designers, manufacturers, companies who fall into the category of a UAS 3PSP such as USS or UTM service providers, and MNOs interested in utilizing their network to serve the emerging UAS space are encouraged to get involved.

Application interests, business opportunities, and operational needs as they pertain to the communications infrastructure which serve the UAS ecosystem (airframe, air to ground control, operational approval and airspace management) are critical inputs to be shared amongst all parties in the cellular and UAS ecosystem to advance the adoption and evolution of cellular networks for UAS.

For further information about active work streams, referrals to vendors doing work in the cellular enabled UAS space, or to provide contribution in the form of participation or industry/application needs and feedback, please send your inquiry to **smartmobility@gsma.com**

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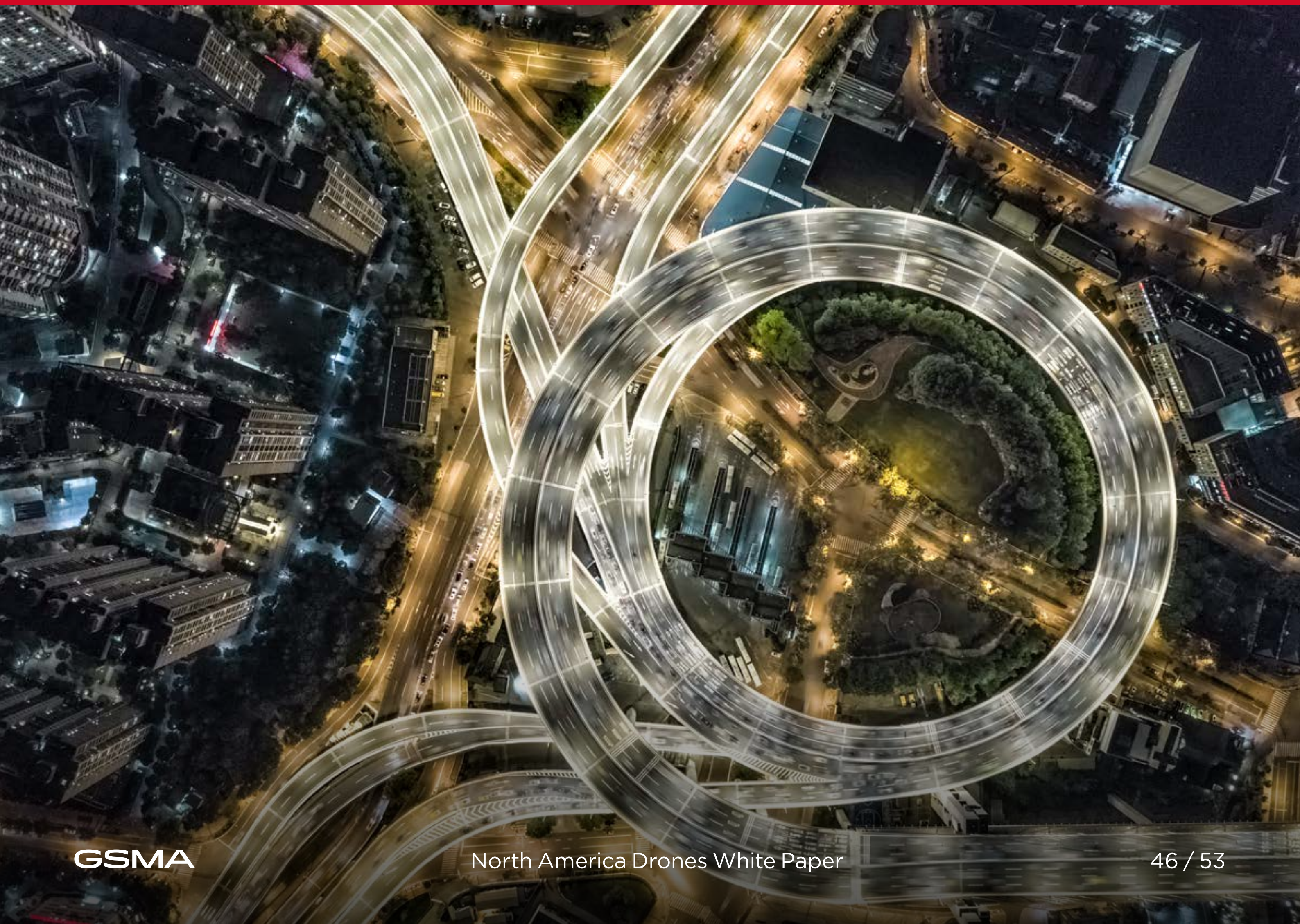
Annex 1: The key 3GPP Working Groups

The 3GPP specification groups are **RAN, CT, and SA** (Service and System Aspects).



The main areas of RAN, CT, and SA are the following:

- **TSG Radio Access Network (TSG RAN) is responsible for the definition of the functions, requirements and interfaces of the UTRA/E-UTRA network in its two modes, FDD & TDD**
- **The TSG Core Network and Terminals (TSG CT) is responsible for specifying terminal interfaces (logical and physical), terminal capabilities (such as execution environments) and the Core network part of 3GPP systems. [https://www.3gpp.org/specifications-groups/ct]**
- **Technical Specification Group TSG Service and System Aspects (TSG-SA) is responsible for the overall architecture and service capabilities of systems based on 3GPP specifications and, as such, has a responsibility for cross TSG coordination. [29]**

Table 2 summarizes some of the most relevant work groups and their main focus areas for the verticals considered in this whitepaper.

WG	Description, relevancy for verticals
RAN 1-4	Radio Access Network architecture is under 3GPP TSG RAN's responsibility. RAN1 specifies the physical layer [30]; RAN 2 specifies layer 2 and Radio layer 3 Radio Resource Control [31]; RAN 3 specifies overall UTRAN/E-UTRAN/NG-RAN architecture and the specification of protocols for the related network interfaces [32] and RAN 4 specifies Radio Performance and Protocol Aspects. [33]
CT1	User Equipment to Core Network protocols. 3GPP TSG CT WG1 (CT1) describes the production, the enhancement and the maintenance of specifications for UE to Core Network interfaces and interfaces within the Core Network for a 5G Core Network (5GCN); an Evolved Packet Core (EPC) ; a 2nd and 3rd generation Core Network (2G CN / 3G CN) for Circuit Switched (CS) and Packet Switched (PS/GPRS); an IP Multimedia (IM) Core Network (CN) Subsystem (IMS) ; a Mission Critical System (MCS); and a Cell Broadcast System (CBS) and a Public Warning System (PWS). [34]
CT3	Interworking. The main objectives of the 3GPP TSG CT WG3 (CT3) are the specification of functionality and related protocols for Interworking between a 3GPP Core Network and external Networks, interworking between PLMNs as well as interworking between PLMN domains; Interworking between IP Multimedia Core Network subsystem and IP Multimedia Core Network subsystems / Circuit Switch networks / external IP networks. The work group also specifies policy and charging control, end-to-end QoS mechanisms; exposure and provisioning of external application related data to the 3GPP network; exposure of network analytic information, session management and network and policy related events within the Core Network and towards external applications making use of Northbound APIs; Data model specification for Policy, Application and Structured data for Exposure; middleware layer and common services between the applications and the underlying 3GPP system for supporting the application layer and allowing the access to service and network capabilities and the provisioning of data. [35]

CT4	Core Network Protocols. the CT4 specifies the protocols within the Core Network and prepare the specifications describing the protocol requirements in the area of: Numbering, Addressing and Identification; Access and mobility management; Session management; Subscription data management; Subscriber authentication; SMS and location services; Data management and Repository; Network slice selection services; NF registration and discovery services; DNS procedures within 3GPP; Separation between Control Plane and the User Plane function; Restoration; and Interconnection between PLMNs. [36]
SA2	The main objective of the architecture group SA2 is to develop the overall 3GPP system architecture and services considering User Equipment, Access Network, Core Network, and IP Multimedia Subsystem. SA2 is responsible for the 5G System and Evolved Packet System (EPS) Architectures including the 3GPP enhancements for multimedia services (including emergency services), IoT, and other market sectors/vertical industries related use-cases. [37]
SA3	The SA3 group defines the requirements and specifies the architectures and protocols for security and privacy in 3GPP systems. It also ensures the availability of cryptographic algorithms in the specifications whereas the SA3-LI subgroup provides the requirements and specifications for lawful interception in 3GPP systems. SA3 is responsible also for security in the 5G System including the 3GPP enhancements for IoT and vertical industries; SA3 develops the security requirements and test cases for network equipment implementing new 5G Network Functions. [38]
SA6	SA6 is the application enablement and critical communication applications group for vertical markets. It provides application layer architecture specifications for 3GPP verticals. Examples of the specifications include architecture requirements, functional architecture, procedures, information flows, interworking with non-3GPP application layer solutions, and deployment models. SA6 considers application layer specifications, with emphasis on critical communication applications (e.g., Mission Critical services for public safety, railways); service frameworks (e.g., Common API Framework, Service Enabler Architecture Layer, Edge Application enablement, Messaging enablement); and enablers for vertical applications (e.g., automotive, drones, smart factories). [39]

Table 2 The 3GPP Work Groups relevant to the verticals of this white paper.

Annex 2: UAS application layer functional model

Functional model of UAS application layer **specified in 3GPP**.

Figure 8 illustrates the overview of functional model of UAS application layer specified in 3GPP. Different functional entities, their relationship and with other enablers layers is shown in the figure.

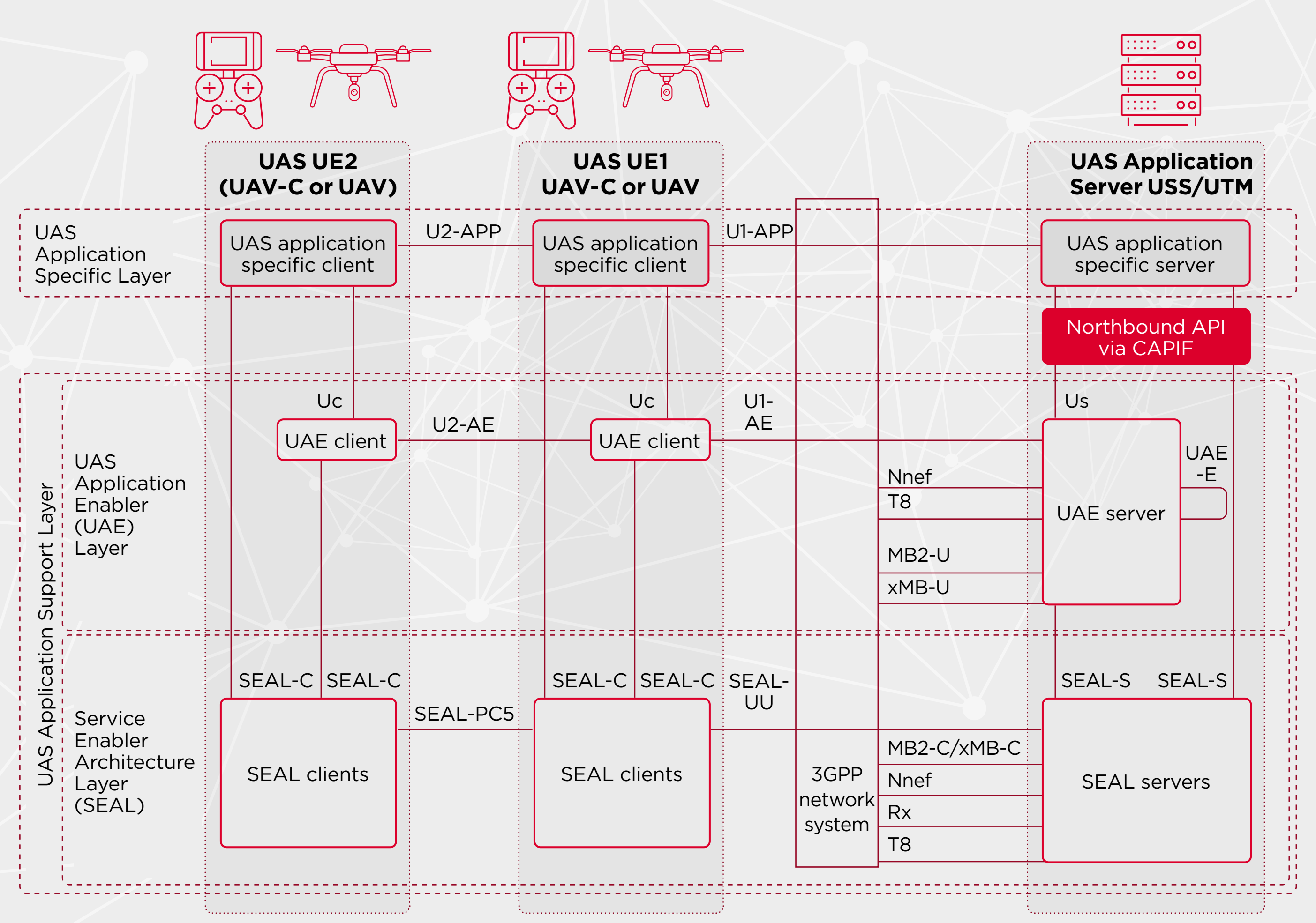


Figure 8 UAS application layer functional model overview

The UAS application layer functional entities for the UAS UE and the UAS application server are grouped into the UAS application specific layer and the UAE layer. The UAE layer offers the UAE capabilities to the UAS application specific layer. The UAS application layer functional model utilizes the SEAL services as specified in 3GPP TS 23.434.

The UAS application server consists of the UAE server, the SEAL servers and the UAS application specific server. The UAE server provides the UAS application layer support functions to the UAS application specific server over Us reference point. The SEAL servers provide the SEAL services to the UAS application specific server/UAE server over SEAL-S reference point. The functionalities of the UAS application specific layer include the USS/UTM and are out of 3GPP scope.

The UAS UE consists of the UAE client, the SEAL clients and the UAS application specific client. The UAE client provides the UAS application layer support functions to the UAS application specific client over Uc reference point. The SEAL clients provide the SEAL services to the UAS application specific client/UAE client over SEAL-C reference point.

The UAS UE1 and the UAS UE2 may be a UAV Controller or a UAV. The UAV Controller can connect to the UAV via a transport independent of 3GPP. The reference point U2-AE supports the interactions between the UAS UEs via PC5. The reference point U1-AE supports at least unicast delivery mode and may support multicast delivery mode. The UAS application server can be the USS/UTM. The reference point U1-AE and U2-AE is based on Uu connectivity as specified in 3GPP TS 23.256. UAV-C to UAV interact over U2-AE (Uu connectivity).

When CAPIF is supported, the UAS application specific server acts as CAPIF's API invoker as specified in 3GPP TS 23.222. The UAE server acts as CAPIF's API exposing function to provide service APIs to the UAS application specific server (e.g. USS/UTM) or another UAE server as specified in 3GPP TS 23.222, or acts as CAPIF's API invoker to consume the service APIs provided by another UAE server.

About the GSMA

The GSMA represents the interests of mobile operators worldwide, uniting more than 750 operators with over 350 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organizations in adjacent industry sectors. The GSMA also produces the industry-leading MWC events held annually in Barcelona, Los Angeles and Shanghai, as well as the Mobile 360 Series of regional conferences.
For more information, please visit the GSMA corporate website at www.gsma.com.

About the GSMA North America Team

Headquartered in Atlanta, Georgia, USA, GSMA North America represents and leads mobile network operators in the United States, Canada, Greenland and the Caribbean. Working alongside some of the mobile industry's most influential companies, GSMA North America aims to increase the region's commercial opportunities and develop a collaborative and socially responsible and ecosystem. In this mission, GSMA North America convenes several leading annual industry events, provides regulatory expertise and technical knowledge to support network optimization.

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