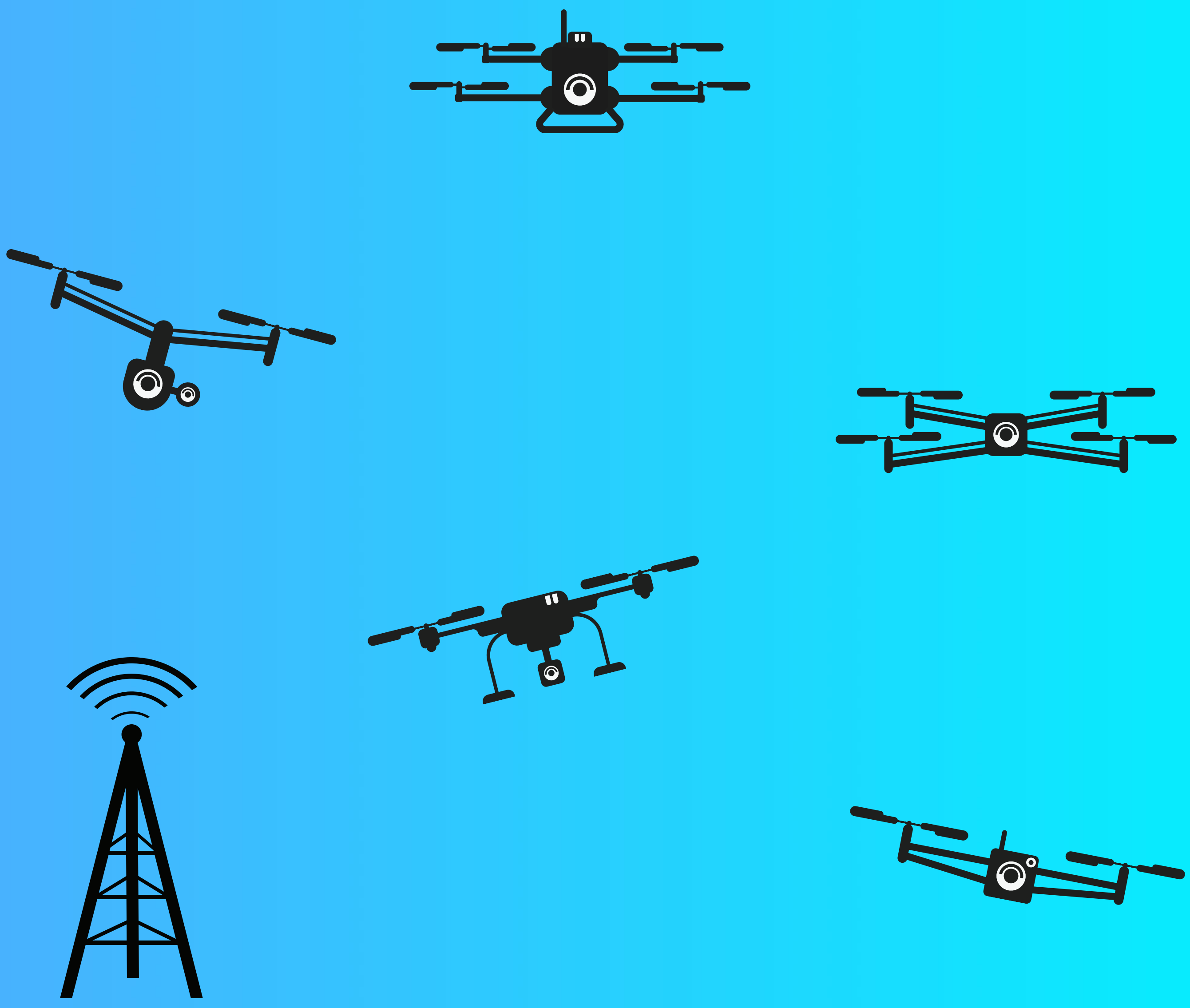
ATIS-I-0000074

# Use of Cellular Communications to Support Unmanned Aerial Vehicle (UAV) Flight Operations



## Abstract

This report addresses the use of cellular communications to address Unmanned Aerial Vehicle (UAV) flight operations in the areas of:

- The Command and Control (C2) interface
- UAV Traffic Management (UTM)
- Remote UAV Identification (ID)
- Detect and Avoid (DAA)

This report reviews existing work that may be relevant to defining requirements and solutions for use of cellular networks in these areas. The report considers requirements that may apply to the North American region. Further, high-level architectural options to support the integration of UAV systems and cellular systems are offered to address the identified requirements.

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# 1. Introduction

The ATIS report *Unmanned Aerial Vehicle (UAV) Utilization of Cellular Services* (ATIS-I-000060), published in 2017, discussed the advantages of using cellular network technology to meet the communication requirements of low altitude Unmanned Aerial Vehicles (UAVs). Since the publication of that report, the industry and regulators have continued to work on a variety of solutions to address the communication needs of UAV and to ensure their safe operation.

Four technical areas have been recognized where communications technology can assist in addressing flight operations of UAVs:

- The Command and Control (C2) interface
- UAV Traffic Management (UTM)
- Remote UAV Identification (ID)
- Detect and Avoid (DAA)

A considerable amount of work has taken place on solutions suitable for short-term deployment that use unlicensed (e.g., Wi-Fi) and other local communication technologies to address these areas.

The technical basis for modern cellular networks is the technical specifications defined by 3GPP. Various work has taken place in 3GPP to make the specifications suitable for supporting UAV communications. Much of this work is described in the ATIS report "Support for UAV Communications in 3GPP Cellular Standards (ATIS-I-000069)" [1]. However, so far 3GPP has not defined system solutions for the four UAV flight operational areas listed above. It is expected that 3GPP Release 17 will work to address the use of cellular networks for UAV flight operations including the C2 interface, UTM, remote identification and DAA.

This report reviews current work that may be relevant to guide the development of 3GPP Release 17 standards. In particular the paper sets out to identify any specifics of the North American regional landscape that need to be accommodated in 3GPP's work.

Successful use of cellular networks to meet UAV flight operation requirements will require an architecture that allows cellular network systems to interact with UAV flight operation systems. This report addresses some high-level considerations in this area.

## 2. Existing Work on Communication Support for UAV Flight Operations

The following table reviews the existing standards and known work in progress which may be relevant when considering the relationship between cellular and UAV systems to support efficient and safe operation of UAVs. The table considers standards that are relevant to communication services for the following areas:

- Command and Control (C2) interface
- UAV Traffic Management (UTM)
- Remote UAV Identification (ID)
- Detect and Avoid (DAA)

| **Standard** | **Status and Availability** | **Main Area of Relevance** | **Comments** |
|---|---|---|---|
| ASTM F3002-14a, Standard Specification for Design of the Command and Control System for Small Unmanned Aircraft Systems [2] | Available | C2 | This specification provides a consensus standard for an application to a nation's governing aviation authority (GAA) for a permit to operate a small unmanned aircraft system (sUAS) for commercial or public use purposes. It is intended for all sUAS allowed to operate over a defined area and in airspace authorized by a nation's GAA. Unless otherwise specified by a nation's GAA, this specification applies only to UAV that have a maximum gross take-off weight of 25 kg (55 lb) or less. This specification covers general command and control (C2) requirements, C2 system spectrum requirements, C2 link requirements, UAV requirements, and fly-away functionality. |
| ASTM Remote ID and Tracking Standard [3] | In progress | ID | The draft standard is intended to support remote identification (Remote ID) and tracking of Unmanned Aircraft Systems (UAS). Implementation of the standard will enable law enforcement personnel and members of the public to remotely identify a UAS using any commercially available handheld device (e.g., a smartphone or tablet).<br><br>As an international regulatory priority, Remote ID ensures accountability of UAS and their operators. The standard is being developed to allow global harmonization, ensure compatibility between systems, maximize adoption and effectiveness, and protect privacy of all parties involved.<br><br>The draft standard supports two primary methods for identification information to be provided for a UAS: broadcast and network. Two technologies (Bluetooth and Wi-Fi) are prescribed in the broadcast method to ensure compatibility with commercially available handheld devices. The network method includes detailed definition of an automatic discovery process that can be used for both Remote ID and UAS Service Supplier to UAS Service Supplier (USS-USS) communication.<br><br>The publicly available “Open Drone ID” message formats are planned to be leveraged in this standard. |

| Standard | Status and Availability | Main Area of Relevance | Comments |
|---|---|---|---|
| ASTM UTM [4] | In progress | UTM | ASTM is currently progressing a new specification for service provided under UAS Traffic Management (UTM).<br><br>The UTM standard is likely to include architecture, assumptions and principles, roles and responsibilities, and services relevant to Flight Planning Service and Strategic Deconfliction Service. The UTM work is coordinated with the ongoing ASTM standards activity on Remote ID and tracking.<br><br>The initial focus of this activity is USS-USS interactions. |
| Eurocontrol: UAS air traffic management (ATM) operational concept [5] | Draft Available | | The UAS air traffic management (ATM) operational concept aims to describe the operational ATM environment in which manned and unmanned aircraft must co-exist safely, including the airspace below 500 feet.<br><br>This document describes the plan in Europe to integrate UAVs into airspace. This is a deliverable of the Concept of Operations for European Unmanned Traffic Management (UTM) Systems (CORUS) project. |
| FLARM [6] | Available 2018 | ID | FLARM is a published UAS electronic ID standard for broadcasting a secure electronic identification and position data from a UAS. This standard has been implemented in several thousands of manned aircraft and UAS worldwide. It implements key requirements of European Union Aviation Safety Agency (EASA) and Federal Aviation Authority (FAA) regulations. Several FLARM implementations and interfaces exist for UAS such as PX4, ArduPilot, MAVLink, DroneCode etc. |
| IEEE P1920.1: Standards for Aerial Communications and Networks [7] | Started March 2019 | C2 | This standard defines air-to-air communications for self-organized ad hoc aerial networks. The communications and networking standards are independent of the type of network (Wireless, Cellular, or other) and are applicable to manned and unmanned, small and large, and civil and commercial aircraft systems.<br>This standard is sponsored by COM/MobiNet-SC - Mobile Communication Networks Standards Committee. |
| IEEE P1920.2: Standards for Vehicle to Vehicle Communications for UAS (Unmanned Aircraft Systems) [8] | Expected to start after P1920.1 | | |
| IEEE P1936.1 Standard for Drone Applications Framework (SDAF) [9] | Started March 2019 | UTM, ID | The standard establishes a framework for support of drone applications. It specifies drone application classes and application scenarios and the required application execution environments.<br>This standard is sponsored by IEEE Communications Society/Access and Core Networks Standards Committee (COM/AccessCore-SC). |

| **Standard** | **Status and Availability** | **Main Area of Relevance** | **Comments** |
|---|---|---|---|
| IEEE P1937.1 Standard Interface Requirements and Performance Characteristics of Payload Devices in Drones (IPDD) [10] | Started March 2019 | UTM, C2 | This standard establishes a framework for Drone interface to payload. It defines the interfaces, performance metrics, provisioning, operation control and management for Drone payload devices.<br>This standard is sponsored by IEEE Communications Society/Access and Core Networks Standards Committee (COM/AccessCore-SC). |
| IEEE P1939.1 Standard for a Framework for Structuring Low Altitude Airspace for Unmanned Aerial Vehicle (UAV) Operations [11] | Started March 2019 | UTM | This standard defines a structure for low altitude airspace that enables safe and efficient Unmanned Aerial Vehicle (UAV) traffic management.<br>It defines UAV capabilities and related infrastructure for UAVs to operate in and comply with low altitude air space regulations.<br>This standard is sponsored by IEEE Communications Society/Access and Core Networks Standards Committee (COM/AccessCore-SC). |
| RTCA AWP-2 - Command and Control (C2) Data Link White Paper [12] | Available | C2 | This White Paper contains the Approach and Considerations for development of Phase 1 Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft System (UAS) Command and Control (C2) Data Link. |

| Standard | Status and Availability | Main Area of Relevance | Comments |
|---|---|---|---|
| RTCA DO-362 - Command and Control (C2) Data Link Minimum Operational Performance Standard [13] | Available 2016 | C2 | The Command and Control (C2) Data Link Minimum Operating Performance Standard (MOPS) (Terrestrial) provides performance requirements for a safety-of-flight Control and Non-Payload Communications (CNPC) function that enables an Unmanned Aircraft System (UAS) pilot to safely manoeuvre the aircraft from the ground.<br><br>The main focus of this MOPS is the technical standards describing how CNPC Data Link Systems can compatibly share the spectrum that has been allocated for their use, yet remain waveform agnostic (i.e., unspecified). There are no interoperability requirements, as these are internal UAS interfaces. Rather, this MOPS provides required electromagnetic compatibility that permits simultaneous operation of federated designs in common spectrum.<br><br>The International Telecommunications Union (ITU) has identified multiple spectrum bands as candidates for use for this C2 Data Link. These include:<br>• L-Band Terrestrial<br>• C-Band Terrestrial<br>• SATCOM in multiple bands<br><br>The UAS C2 Data Link MOPS establishes the performance requirements for both L-Band and C-Band terrestrial networks. This will also include recommendations for a Verification and Validation test program.<br><br>The completed MOPS contains equipment performance requirements under standard conditions for the following:<br>• Common characteristics<br>• The baseline system that was used for verification and validation efforts<br>• Manufacturer-specific requirements for designs that vary from the baseline system described within.<br><br>The environment performance section provides requirements for both airborne and ground equipment, since both are needed for the complete link.<br><br>As there was no Minimum Aviation System Performance Standard (MASPS) that preceded this MOPS, there are over a dozen appendices that provide assumptions and derived flow-down requirements that would have historically come from a MASPS. |
| RTCA DO-377 - Minimum Aviation System Performance Standards for C2 Link Systems Supporting Operations of Unmanned Aircraft Systems in U.S. Airspace [14] | Available March 2019 | | This document contains the Minimum Aviation System Performance Standards for a C2 Link System connecting a Control Station and a UAV. It covers UAV operating within line of sight and beyond the line-of-sight. This document specifies system characteristics, i.e., it is design independent and should be useful to UAV operators, equipment manufacturers, and the FAA. |

| Standard | Status and Availability | Main Area of Relevance | Comments |
|---|---|---|---|
| RTCA WP-1 Detect & Avoid (DAA) White Paper [15] | Available | DAA/UTM | This White Paper contains the Approach and Considerations for development of Phase 1 Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft System (UAS) Detect & Avoid. |
| RTCA DO-365 - Minimum Operational Performance Standards for Detect & Avoid Systems [16] | Available 2017 | DAA/UTM | The Detect & Avoid (DAA) Minimum Operating Performance Standard (MOPS) provides performance requirements for Unmanned Aircraft System (UAS) that operate 500 feet above ground level.<br><br>The focus of this MOPS is on unmanned aircraft to be able to fly in airspace frequented by commercial transport and general aviation aircraft. The technology needed to detect this range of aircraft to prevent the risk of collision is outlined. Future versions of this document are expected to address operational scenarios applicable to smaller UAS needs, as well as to other DAA architectures.<br><br>This MOPS contain required performance for equipment (sensors, radar), ADS-B data, unmanned aircraft DAA processor output data, airborne active surveillance requirement, DAA track management/alerting, ownership intent information, preventive/corrective/warning manoeuvres, and display requirements for the pilot in control. More importantly, there are discussions and analysis about the requirements on command and non-payload communications to support the requirements of a DAA system which would be useful for extending these analogous concepts to the small UAS framework.<br><br>There are over a dozen appendices that provide assumptions, sample algorithms, example functional description, modelling and simulation work used to validate DAA alerting algorithms, and sensor performance assumptions. |
| 3GPP 22.125 - Unmanned Aerial System Support in 3GPP [17] | Available 2018 | UTM, DAA, ID | This specification covers requirements for support of UAV flight operations in 3GPP specifications. The contents include:<br>• General<br>– Requirements for Mobile Network Operator (MNO) and 3GPP standard to report information about the UAV and UAV Controller to the UTM<br>– Requirements for MNO and 3GPP to communicate and enforce authorization of the UAS operation by the UTM<br>• Centralized UAV Traffic Management<br>– How centralized UTM interacts with UAS via 3GPP network<br>• Decentralized UAV Traffic Management<br>– Local broadcast solutions for UAV management and collision avoidance<br>• Security<br>– Confidentiality, identity spoofing, integrity protection, lawful intercept |

| Standard | Status and Availability | Main Area of Relevance | Comments |
|---|---|---|---|
| 3GPP TR 22.829 - Enhancement for Unmanned Aerial Vehicles [18] | Estimated Available Q3 2019 | UTM, C2 | This is the 3GPP Technical report on use cases and analysis of UAV capabilities that may require enhanced 3GPP support. This report is expected to be completed no later than Q3 of 2019, and the normative 3GPP requirements basing on this report will defined by end of 2019. This report not only includes the use cases of various cellular connected UAV applications and their the 3GPP communication service requirements, but also includes the use case and requirements for supporting UAV C2 communication as well as the communication between UAV & UAV controller to UTM.<br><br>Particularly note section 7 which embodies a summary of consensus reached at the end of the study item. |
| 3GPP TS 36.777 - Enhanced LTE support for aerial vehicles [19] | Available | | Though this does not directly address flight operational applications, it does cover the general capabilities of LTE to support UAV communication. |
| 3GPP "Study on supporting Unmanned Aerial Systems Connectivity, Identification, and Tracking" (FS_ID_UAS-SA2) [20] | Est Approval Q1 2020 | UTM, ID, C2 | The 3GPP system can be used to enable UAS identification and tracking and to support UAS command and control functions. Examples of such support include:<br>• Enabling UAS components such as the UAV and the UAV(s) controller to establish the necessary connectivity between each other and with an Unmanned Aerial System Traffic Management (UTM)<br>• Allowing authorised users (for example, air traffic control and public safety agencies) to query the identity and metadata of a UAV and its UAV controller via Unmanned Aerial System Traffic Management (UTM). The UTM stores the data required for UAS(es) to operate. Air traffic control agency uses the UTM server to authorise, enforce, and regulate UAS operation. |
| 3GPP "Study on application layer support for Unmanned Aerial System (UAS)" (FS_UASAPP) [21] | Est Approval Q1 2020 | UTM, ID, C2 | With the service requirements resulting from previous work (see TS 22.125), the 3GPP system will play a role in supporting the UAS Traffic Management (UTM) authorization, identification and tracking of Unmanned Aerial Systems (UAS). A study is required to understand the impact on the application layer to support the scenarios identified, in particular the application support/enabler functionalities for UTM and the service interactions between UAS and the UTM (e.g., fly route authorization, location management, and group communication support). |

# 3. High Level Architectural Approaches

## 3.1 3GPP Requirements and Grouping of Possible Architectural Approaches

3GPP requirements for UAV flight operations are defined in specification 22.125 which was approved in Release 16. In this section, possible architectural approaches to address the requirements in 22.125 are examined.

In this analysis it has been determined that there are three main architectural approaches that could address 22.125 requirements:

- Group 1: Architectural approaches that use IP traffic over 3GPP/Internet
- Group 2: Architectural approaches based on direct communication over 3GPP interfaces between nodes in close physical proximity
- Group 3: Architectural approaches that require tighter integration of 3GPP and UAV technology – e.g., linking of identities between UAVs and 3GPP UEs or tight integration of 3GPP communication with the UAV's navigation system

In the following subsections each of these groups will be discussed in more detail.

## 3.2 Architectural approaches that use IP traffic over 3GPP/Internet

Some requirements may be met by using "over the top" IP protocols to communicate between the UAS and other entities. Using IP has several advantages, for example:

- IP communication is already supported in 3GPP networks
- IP can be transported over many bearer technologies allowing flexible choice of bearer technology depending on the circumstances
- IP traffic can be routed anywhere within an IP network allowing nodes to be flexibly located

Example requirements from 22.125 where an over the top IP solution may be appropriate include:

- "The 3GPP system shall provide a mechanism for a UTM to provide route data, along with flight clearance, to a UAV"

- “The 3GPP system shall enable a UTM to send route modification information to a UAS with a latency of less than 500ms”

The general public Internet normally treats IP traffic on a “best effort” basis without any performance guarantees. To ensure IP services are suitable for UAV flight operations, the quality of service (QoS) applied to IP traffic may need to be managed.

If IP is used to deliver instructions to the UAS, then UASs must be trusted to obey instructions as there would be no technical enforcement mechanism in the 3GPP system.

## 3.3 Architectural approaches based on direct communication over 3GPP interfaces between nodes in close physical proximity

Some requirements are similar to those for “decentralized traffic management” and lend themselves to local broadcast-based solutions. Example requirements from 22.125 which may be addressed by direct communication include:

- “The 3GPP system shall enable a UAV to broadcast the following identity data in a short-range area for collision avoidance: UAV type, current location and time, route data, operating status.”
- “The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service which can support the maintenance of UAV to UAV separation. UAVs are considered separated if they are at a horizontal distance of at least 50m or vertical distance of [30]m or both.”

A suitable architectural approach could be to broadcast direct UAV to UAV or UAV to ground communication using 3GPP protocols. The exact form of the direct interface is for further study. To send and receive data, the UAVs must access the 3GPP-specified direct communication mechanism. The higher layers of the solution could be similar to other work using local transmission (e.g., ASTM remote ID) but with the lower layers replaced with 3GPP protocols.

## 3.4 Architectural approaches that require tighter integration of 3GPP and UAV technology

This approach covers situations where data and operations need to be tightly integrated between the 3GPP network and the UAS. Examples of data that could be integrated include identity, location, flight plans, and UTM addressing. The technical solutions are specific to 3GPP to allow for the integration.

Examples of 22.125 requirements that may require tighter integration between the 3GPP and UAV technology include:

- "The 3GPP system should enable UTM to associate the UAV and UAV controller, identify them as a UAS."
- "The 3GPP system should enable an MNO to augment the data sent to a UTM with the following: network-based positioning information of UAV and UAV controller."
- "3GPP system shall enable an MNO to enforce the authorization for a UAS to operate (e.g., by enabling or disabling communication between the UAV and UAV controller; or by establishing a reliable route within 3GPP network to deliver the commands/control messages between the UAV and UAV controller)."

### *3.4.1 Architectural Model of the UAV*

A simple architectural model of a UAV is shown below. In order to support integration of data between the flight control function and 3GPP user equipment (UE) function, the interface between the functions must support a rich set of capabilities. The nature of this interface is for further study.

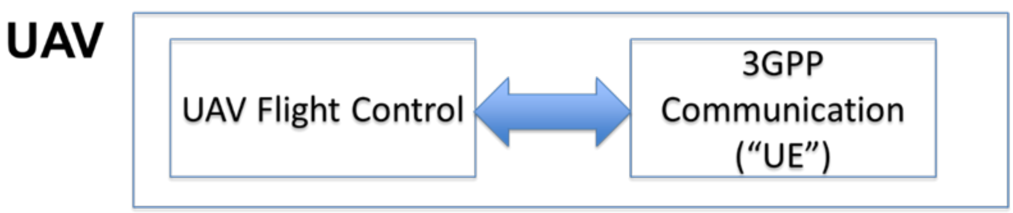


Figure 1: Architectural Model of UAV

There are questions of how to ensure trust and correct behavior within the UAS (e.g., if the MNO is attempting to enforce UTM policies).

### *3.4.2 Network Model*

A simple network model is shown below. It is assumed that the UTM is centralized and connected to the 3GPP core network over an IP backbone.

The gateway between the 3GPP core network and the UTM is an important function to:

- Manage access rights of the UTM
- Integrate different 3GPP information which may be collected from different 3GPP functions (e.g., location, identity)
- Provide communication to the UAS
- Provide the UTM with the ability to disable UAS communication/operation


Figure 2: Architectural Model of the Network

## 4. Conclusions

In mobile cellular standards, particularly 3GPP, the goal is to define specifications that achieve multi-vendor interoperability over the standardized interfaces. This should also be the goal when 3GPP approaches standardization of features to support UAV flight operations.

A review of existing standards activities related to UAV flight operations was carried out to determine potential overlap with the scope of upcoming 3GPP work. No work that directly addresses support of UAV flight operations over cellular networks or similar licensed technology was found during this review. However, it is noted that the ASTM work on the use of unlicensed radio technology to support remote identification and UTM does have support from the UAV industry and aviation regulators. It is believed that this work will become important in the North American region and there may be synergy with 3GPP's work.

The requirements defined in 22.125 for support of UAVs are diverse and meeting them all may require a combination of different architectural approaches. Three possible approaches are identified in this report. 3GPP will need to select which architectural approaches to pursue for standardization. One important question is whether support for UAV flight operations should include the use of local 3GPP-based radio interfaces. Another important question is the extent to which 3GPP should define the complete application layer of UAV flight operation functions as opposed to exposing system capabilities and allowing the application to operate “over the top”.

In order to ensure that 3GPP standards are relevant and useful to the UAV community, particular attention should go in to ensuring that UAV experts contribute to the 3GPP standardization process.

## 5. Abbreviations

| | |
|---|---|
| ATM | Air Traffic Management |
| C2 | Command and Control |
| CNPC | Control and Non-Payload Communications |
| DAA | Detect and Avoid |
| EASA | European Union Aviation Safety Agency |
| FAA | Federal Aviation Authority |
| GAA | Governing Aviation Authority |
| ID | Identification |
| IP | Internet Protocol |
| MASPS | Minimum Aviation System Performance Standard |
| MNO | Mobile Network Operator |
| MOPS | Minimum Operational Performance Standards |
| QoS | Quality of Service |
| sUAS | Small unmanned Aircraft System |
| UAS | Unmanned Aircraft System |
| UAV | Unmanned Aerial Vehicle |
| UE | User Equipment |
| USS | UAS Service Supplier |
| UTM | UAV Traffic Management |

# 6. References


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[5] Eurocontrol: Unmanned Aircraft Systems (UAS) ATM Integration Operational Concept https://www.eurocontrol.int/publication/unmanned-aircraft-systems-uas-atm-integration

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