ARCHITECTURAL FRAMEWORK DOCUMENT:

UAS OVER 5G NETWORK

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Contents

Figures

Tables

Introduction

The Open Generation Consortium was created to accelerate 5G innovation by convening industry innovators, end users, and researchers to identify and solve hard challenges and to demonstrate live enterprise use cases.

Scope

The objective of the architecture framework document (UAS over 5G Network) is to describe a system architecture for support of Unmanned Aircraft Systems (UASs). The architecture framework is based on industry standards including 3rd Generation Partnership Project and other standard bodies that support UASs. The present document describes the 5G network components, functions, and specifications required to support solutions that will realize the technical requirements of UAS use cases. The present document may be used as a reference by other Open Generation working groups and project teams.

References

References in this document are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

3GPP Standards

- **TS** 22.104 Service requirements for cyber-physical control applications in vertical domains
- **TS** 22.125 Unmanned Aerial System (UAS) support in 3GPP; Stage 1
- **TS** 22.261 Service requirements for the 5G system
- **TS** 23.203 Policy and Charging control Architecture
- **TS** 23.256 Support of UAS connectivity, identification, and tracking; Stage 2 (R17)
- **TS** 23.304 Proximity based Services (ProSe) in the 5G System (5GS)
- **TS** 23.501 System architecture for the 5G System (5GS)
- **TS** 23.502 Procedures for the 5G System (5GS)
- **TS** 23.548 5G System Enhancements for Edge Computing; Stage 2
- **TS** 23.558 Architecture for enabling Edge Applications
- **TS** 33.256 Security aspects of Uncrewed Aerial Systems (UAS) (Release 17)
- **TS** 33.501 Security architecture and procedures for 5G System
- **TS** 37.355 LTE Positioning Protocol (LPP)
- **TS** 38.305 NG-RAN; Stage 2 functional specification of UE positioning in NG-RAN
- **TS** 38.455 NG-RAN; NR Positioning Protocol A (NRPPa)
- RP-213600 Release 18, NR support for UAV (Uncrewed Aerial Vehicles)

O-RAN

- **O-RAN.WG1.O-RAN-Architecture-Description-v05.00** O-RAN Architecture Description 5.0 - July 2021

RTCA

- DO 365B MOPS for Detect and Avoid (DAA) Systems
- DO 377A MASPS for C2 Link Systems Supporting Operations of UAS in U.S. Airspace

ASTM

- F3411 Standard Specification for Remote ID (RID) and Tracking
- F3442 Standard Specification for Detect and Avoid System Performance Requirements

FAA

- Phase 2 progress report UTM Pilot Program (UPP)
- DEPARTMENT OF TRANSPORTATION Federal Aviation Administration 14 CFR Parts 1, 47, 48, 89, 91, and 107 [Docket No.: FAA–2019–1100; Notice No. 20–01] RIN 2120–AL31 Remote Identification of Unmanned Aircraft Systems.

IEEE

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[2] Nokia Bell labs trial: “Drone control over public LTE,” URL: https://www.youtube.com/watch?v=twsDFQqS7vU.

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[4] R. Amorim, H. Nguyen, J. Wigard, I. Z. Kovács, T. B. Sørensen, D. Z. Biro, M. Sørensen, and P. Mogensen, "Measured uplink interference caused by aerial vehicles in LTE cellular networks," in IEEE Wireless Commun. Lett., vol. 7, no. 6, pp. 958-961, Dec. 2018, doi: 10.1109/LWC.2018.2841386.

[5] A. Garcia-Rodriguez, G. Geraci, D. Lopez-Perez, L. G. Giordano, M. Ding, and E. Bjornson, ‘‘The essential guide to realizing 5G-connected UAVs with massive MIMO,’’ IEEE Commun. Mag., vol. 57, no. 12, pp. 84-90, Dec. 2019.

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Definitions and Abbreviations

Abbreviations

Acronym	Explanation
3GPP	3rd Generation Partnership Project
5GC	5G Core Network
5GS	5G System
5QI	5G QoS Identifier
ADS-B	Automatic Dependent Surveillance Broadcast
AKA	Authentication and Key Agreement
AMF	Access and Mobility Function
AN	Access Network
API	Application Programming Interface
ASTM	American Society for Testing and Materials
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
D2D	Device-to-Device
DAA	Detect and Avoid
DC	Direct Current
DN	Data Network
DNN	Data Network Name
ETSI	European Telecommunications Standards Institute
FAA	Federal Aviation Administration
GBR	Guaranteed Bit Rate
GCS	Ground Control Station
gNB	Next Generation NodeB

Acronym	Explanation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GTP	GPRS (General Packet Radio Service) Tunnelling Protocol
IMU	Inertial Measurement Unit
IoT	Internet of Things
ISG	Industry Specification Group
LiPo	Lithium Polymer
LMF	Location Management Function
LOS	Line of Sight
LPP	LTE Positioning Protocol
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NG-AP	NG Application Protocol
NG-RAN	Next Generation Radio Access Network
NRPPa	New Radio Positioning Protocol "a"
O-CU-CP	O-RAN Central Unit Control Plane
O-CU-UP	O-RAN Central Unit User Plane
O-DU	O-RAN Distributed Unit
O-RAN	Open Radio Access Network
O-RU	O-RAN Radio Unit
PDU	Protocol Data Unit

Acronym	Explanation
ProSe	Proximity Services
PRS	Positioning Reference Signal
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RIC	Radio Intelligent Controller
RID	Remote Identification (Remote ID)
RPIC	Remote Pilot in Command
RT	Real Time
RTCA	Radio Technical Commission for Aeronautics
RTT	Round-Trip Time
SMO	Service Management and Orchestration
TX/RX	Transmitter/Receiver
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System (referred to in 3GPP as Uncrewed Aerial System)
UAV	Unmanned Aerial Vehicle (referred to in 3GPP as Uncrewed Aerial Vehicle)
UE	User Equipment
UPF	User Plane Function
USS	UAS Service Supplier
UTM	UAS Traffic Management
UUAA	UAV USS Authentication Authorization
WI	Work Item

Definitions

Term	Definition
C2 Communication	The user plane link to convey messages with information of command and control for UAV operation between an unmanned aerial vehicle (UAV) controller and a UAV.
PC5	The direct communication between vehicle and other devices uses so-called PC5 interface. PC5 refers to a reference point where the user equipment (UE)—e.g., mobile handset—directly communicates with another UE over the direct channel. In this case, the communication with the base station is not required.
Remote ID of UAS	The ability of a UAS in flight to provide identification and tracking information that can be received by other parties; to facilitate advanced operations for the UAS (such as beyond visual line of sight operations as well as operations over people); and to assist regulatory agencies, air traffic management agencies, law enforcement, and security agencies when a UAS appears to be flying in an unsafe manner or where the UAS is not allowed to fly. The Remote ID information payload may include the Serial Number or Session ID assigned to the UAV, location of the UAV controller, emergency status indication, and so on.
UAS	Composed of UAV and related functionality, including C2 links between the UAV and the controller, the UAV, and the network, and for Remote ID. A UAS is composed of a UAV and a UAV controller.
UAS NF	A 3rd Generation Partnership Project (3GPP) UAS network function for support of aerial functionality related to UAV identification, authentication/authorization, and tracking, and to support Remote ID.
UAV Controller	Enables a drone pilot to control a UAV. UAV controller is also known as GCS.
Uncrewed	An aircraft operated without the possibility of direct human intervention from within or on the aircraft. (14 CFR §1.1, changed "unmanned" to "uncrewed").
USS	An entity that provides services to support the safe and efficient use of airspace by providing services to the operator/pilot of a UAS in meeting UTM operational requirements. A USS can provide any subset of functionality to meet the provider's business objectives (e.g., UTM, Remote ID).
UTM	A set of functions and services for managing a range of autonomous vehicle operations.
UUAA	UAV USS authentication and authorization procedure of the UAV to ensure that the UAV has successfully registered with a USS and has therefore been authorized for operations by the USS. A UAV is authenticated and authorized by the USS via a UAV USS Authentication Authorization (UUAA) procedure with the support of the 3GPP system before connectivity for UAS services is enabled.
Visual Observer	A person who is designated by the remote pilot in command to assist the remote pilot in command and the person manipulating the flight controls of the small UAS to see and avoid other air traffic or objects aloft or on the ground.

Overview—Systems and Standards

Aviation

The previously used terminology for flying aircraft without a crew on-board was "uncrewed aerial vehicle," a term that is still used in some 3rd Generation Partnership Project (3GPP) documents. However, the Federal Aviation Administration (FAA) now legally recognizes all such flying vehicles as "aircraft," and thus the current FAA terminology is "unmanned aircraft" (UA; see 14 CFR §1.1). The Department of Defense uses the term "remotely piloted aircraft." In this document, we will attempt to consistently use "uncrewed aircraft" and "Uncrewed Aerial System" unless we are referencing another document from one of these groups.

An aircraft is only part of a complete system. Thus, the term "uncrewed aircraft system" consists of (1) the UA, (2) the ground control station (GCS), and critically (3) the communication link between these two elements. Therefore, one should try to avoid making statements such as the "5G network connects to the UAS," as the network is inherently a key component of the UAS.

The communications link between UA and GCS is for telemetry data coming from the UA to the GCS and commands going from GCS to the UA. This two-way communications link is generally referred to as "command and control" (C2) by the original military drone users. This term was refined in Radio Technical Commission for Aeronautics (RTCA) SC-228 to be "command and non-payload communication" to clearly delineate the part of the communications link that was critical to safety of flight between the GCS and the UA, which separated out the mission data communications that may contain high-bandwidth but lower-priority data such as video camera streams or other sensor data.

One of the oldest rules of flight since the invention of the airplane is that "vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft" (14 CFR §91.113). The introduction of UA makes this more challenging, as there is no pilot on-board to perform this task. An obvious solution might be to add a camera on-board the UA; however, the FAA legal office has ruled that the human eyeball performing "see and avoid" may be augmented only by normal glasses and not by any electronic means (Reference: N8900.227). Thus, the term "detect and avoid" (DAA) was coined as a replacement concept. However, DAA is not yet recognized via regulation, and thus waivers must be granted to either 14 CFR 91.113 or 14 CFR 107.31.

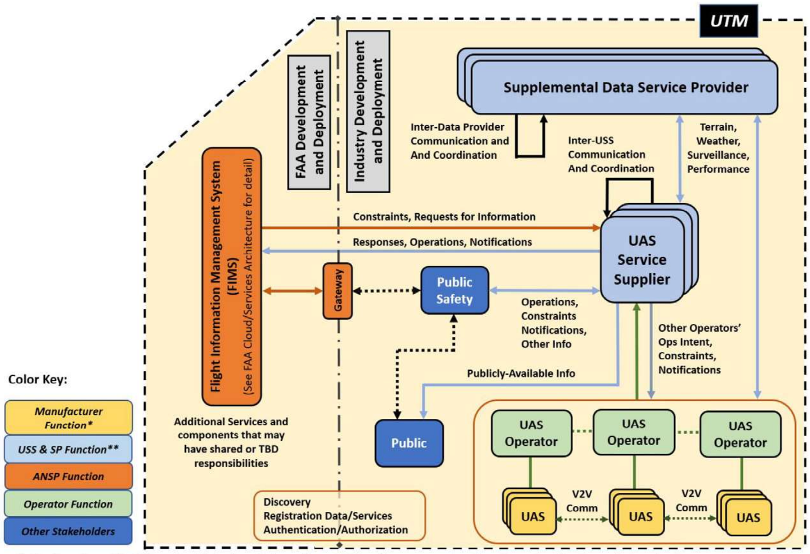
Since the development of the radar system during World War II, aviation has had a requirement to differentiate "friend from foe." The traditional technology used for this requirement has been the transponder. A ground-based secondary surveillance radar can interrogate an aircraft transponder and, by measuring the round-trip time and the angle, determine the position of the aircraft. Automatic Dependent Surveillance Broadcast (ADS-B) evolves the surveillance concept by broadcasting the onboard global positioning system (GPS) position of the aircraft. If all crewed aircraft had ADS-B equipage, then DAA would not be that difficult an issue. Unfortunately, the mandate to carry ADS-B equipment is required only in certain airspaces (14 CFR §91.225) and the cost of equipage is expensive. UASs must be able to detect aircraft that are not equipped with transponders or ADS-B, which are called "noncooperative" aircraft.

Noncooperative DAA is divided into systems that work on-board the aircraft and from the ground. Radar is generally recognized as the most reliable detection method, but also the most expensive. There has been some success with acoustic systems (Reference: TASA). Camera-based systems are often referred to as "electro-optical systems" and have generally required augmentation to be effective, because the speed of aircraft makes them less effective.

There is a significant demand for commercial use of small UASs. The FAA established a set of rules for these aircraft. In 2016, 14 CFR §107 was first published defining a "small, unmanned aircraft system" as one that has a UA that weighs less than 55 pounds (25 kg). These rules allow for commercial use of UASs within extremely strict operational limitations. These limitations include flight within 400 feet of the ground or a ground obstacle, daytime operations, no flight over people, and flight within visual line of sight of the pilot (14 CFR §107). Each of these restrictions can be waivered through a safety mitigation process; however, waivers to multiple of these restrictions are rarely granted.

An additional element if drones are to fly broadly beyond visual line of sight (BVLOS) is to have some management of traffic services. The FAA does not wish to provide air navigation or traffic services for small UASs. Therefore, the concept of Unmanned Aircraft System Traffic Management (UTM) was created. The UTM notional architecture diagram is shown below in **Figure 1** (Reference: UTM Pilot Program Phase 2: Progress report). The UTM concept has expanded to include a wide range of services for UAS operators. A private provider of UTM services is called a "UAS Service Supplier" (USS). A USS gathers weather and traffic information from various sources and then analyzes and provides service to UAS operators to help with the safety of flight.

Navigation requirements specific for UASs are still in development. Small UASs flying under 14 CFR 107, including commercial operations, do not have a specific navigation requirement. However, in general, commercial aviation operators flying instrument flight rules are required to have two independent forms of navigation (14 CFR §121.349, 14 CFR §135.165, 14 CFR §91.511). These rules were written with crewed aircraft in mind but have not yet been modified for uncrewed aircraft. A critical



* The Operator and/or USS may be able to characterize and bound UAS performance needs and requirements without manufacturer input.
** Operators may be able to self-provision certain services.

FIGURE 1: UTM NOTIONAL ARCHITECTURE

part of any global navigation satellite system (GNSS) is not only the receiver but the space and ground support segments. Thus, another challenge for UASs is identifying a second form of navigation that meets the size, weight, cost, and power requirements of the mission.

3GPP System

The 3GPP unites seven telecommunications standards development organizations known as "Organizational Partners," and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies. The Organizational Partners are:

- Association of Radio Industries and Businesses (ARIB)
- Alliance for Telecommunications Industry Solutions (ATIS)
- China Communications Standards Association (CCSA)
- European Telecommunications Standards Institute (ETSI)
- Telecommunications Standards Development Society (TSDSI)
- Telecommunications Technology Association (TTA)
- Telecommunication Technology Committee (TTC)

The project covers cellular telecommunications technologies including radio access and core network and service capabilities, which provide a complete system description for mobile telecommunications. The 3GPP specifications also provide hooks for non-radio access to the core network and for interworking with non-3GPP networks.

3GPP specifications and studies are contribution driven, by member companies, in working groups, and at the Technical Specification Group level.

The three Technical Specification Groups in 3GPP are:

- Radio Access Networks
- Services & Systems Aspects
- Core Network & Terminals

The diagram in **Figure 2** shows components of 3GPP systems for 4G and 5G technology.

Figure 3 shows a high-level architecture diagram of UAS over 3GPP systems.

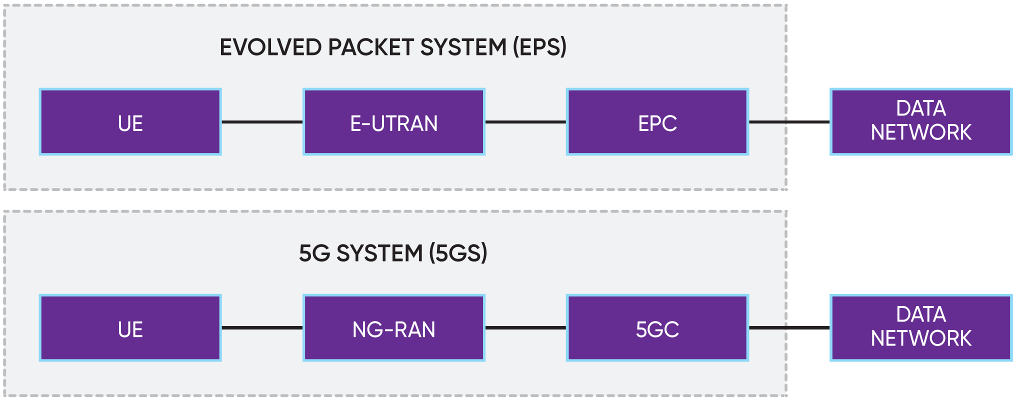


FIGURE 2: EPS AND 5G SYSTEM

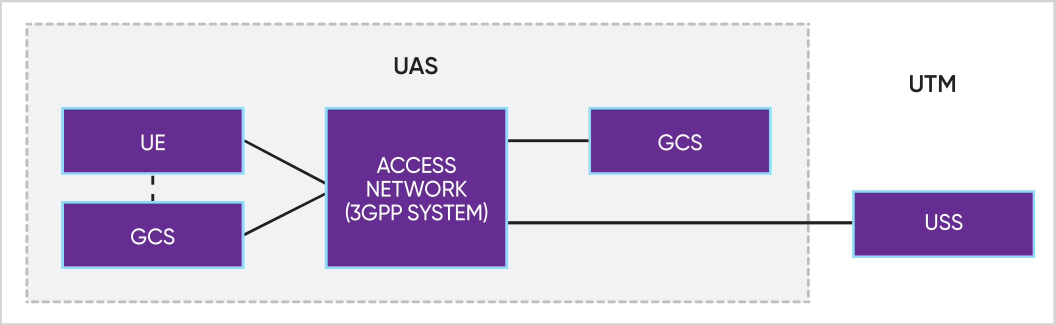


FIGURE 3: UAS OVER 3GPP NETWORK

RTCA

RTCA is a private, not-for-profit association founded in 1935 as the Radio Technical Commission for Aeronautics, a premier public-private partnership venue for developing consensus among diverse, competing interests on critical aviation modernization issues in an increasingly global enterprise. RTCA products serve as the basis for government certification of equipment used by the tens of thousands of aircraft flying daily through the world's airspace. As a standards development organization, RTCA works with the FAA to develop comprehensive, industry-vetted, and endorsed standards that can be used as means of compliance with FAA regulations.

SC-228, Minimum Performance Standards for UAS, is working to develop the Minimum Operational Performance Standards (MOPS) for DAA equipment and a C2 Data Link MOPS establishing cellular, L-band, and C-band solutions.

ASTM

The American Society for Testing and Materials (ASTM) International is a standards development organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. It does not play any role in requiring or enforcing compliance with its standards; however, the standards may become mandatory when referenced by an external contract, corporation, or government. ASTM provides high-level standards for various industries. The standards vary from more precise and technical to more conceptual and visionary.

Published ASTM standards include:

- Guide for Remote Pilot in Command (RPIC) of UAS
- Ensuring dependability of software in UAS
- Unmanned flight manual for UAS
- UAS Registration and Marking (for large UAS)
- Design, construction, and verification of lightweight UAS
- UTM/USS Interoperability
- Remote Identification of UAS
- Maintenance of Small UAS

FAA

The FAA's authority is granted by 49 U.S. Code § 40103:

The Administrator of the Federal Aviation Administration shall develop plans and policy for the use of the navigable airspace and assign by regulation or order the use of the airspace necessary to ensure the safety of aircraft and the efficient use of airspace. The Administrator may modify or revoke an assignment when required in the public interest.

Where the term "navigable airspace" is defined to be:

Airspace above the minimum altitudes of flight prescribed by regulations under this subpart and subpart III of this part, including airspace needed to ensure safety in the take-off and landing of aircraft.

This has been interpreted explicitly to not include any airspace that is indoors or within a "drone cage." Thus, later reference to an indoor use case will not be subject to any FAA regulations or policy if it can be ensured to always remain inside.

Chapter 1 of Title 14 of the Code Federal Regulations covers regulations of FAA. 14 CFR 107 (a.k.a. Part 107) addresses FAA regulations focused on the rules for commercial use for uncertified UASs. An uncertified aircraft is an aircraft that has not been granted an Airworthiness Certificate by a federal government agency. A small UAS is defined to be a UAS that weighs less than 55 pounds. Part 107 generally does not allow for flight over people or BVLOS without a waiver. The vast majority of Part 107 drones use unlicensed spectrum for C2.

14 CFR 91 contains General Operating and Flight Rules and applies to aircraft not covered under 14 CFR 107. 14 CFR 91.113 calls for "vigilance [to] be maintained by each person operating an aircraft so as to see and avoid other aircraft." This is a particular challenge for drones to fly BVLOS. The phrase "detect and avoid" has been coined to take the place of this need to "see and avoid" but has not been codified in any regulation because it is still in the experimental phase.

14 CFR 119 addresses Certification: Air Carriers and Commercial Operators more generally. 14 CFR 135 is Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons on Board Such Aircraft. 14 CFR 135 is what most large operators of UASs will likely operate under if their operation does not fit under 14 CFR 107. That is, drones with Airworthiness Certificates or drones heavier than 55 pound that want to do commercial activity on a regular basis will typically be operating under the rules of 14 CFR 135.

Architecture Model and Concepts

UAS Support in 5G System (5GS) Architecture

The 3GPP Standard TS 23.256 specifies architecture enhancements for supporting UAS connectivity, identification, and tracking, according to the use cases and service requirements defined in 3GPP TS 22.125. The diagram in **Figure 4** shows the various building blocks of 5GS and UASs.

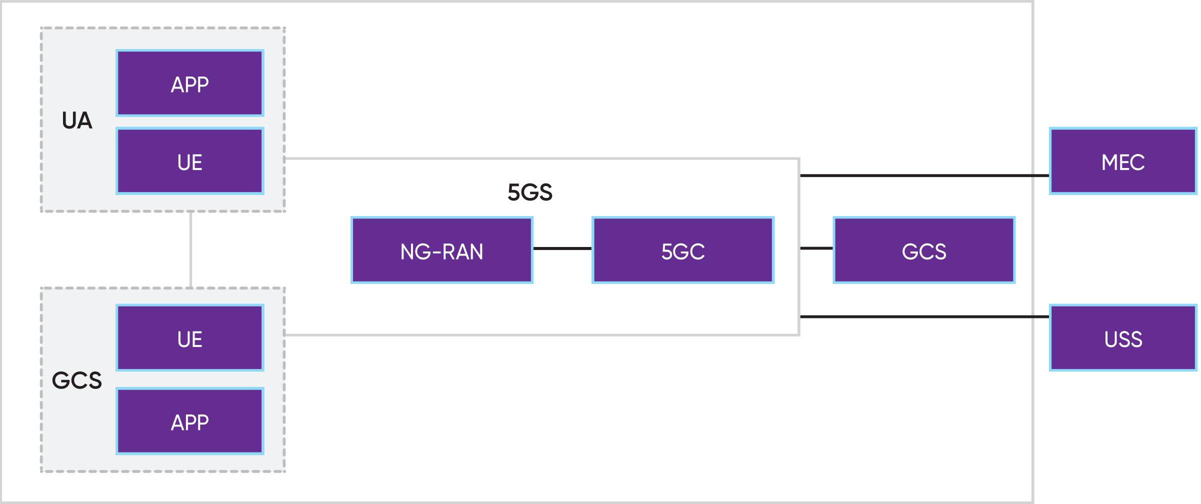


FIGURE 4: UAS REFERENCE ARCHITECTURE OVER 5GS

Functional Entities

UNCREWED AIRCRAFT COMPONENTS

The major categories of aircraft include airplane, rotorcraft, and lighter-than-air. Each of these categories is also a valid UA. However, a hybrid of airplane and rotorcraft has the advantages of vertical take-off and landing while having the superior range of an airplane over a pure rotorcraft.

Most small UAs are powered by Lithium Polymer (LiPo) batteries because of their ability to discharge a large amount of power over a short amount of time while preserving a reasonable weight. Some larger drones incorporate petroleum-based liquid or hydrogen fuels for higher energy density.

Electric Direct Current (DC) motors are very popular in a UA. They are simple, reliable, and lightweight. The most efficient are brushless DC motors that require an electronic speed control to vary the current in the motor windings to control the speed.

UA frames may be of various materials, but because being lightweight is a significant concern for aircraft, carbon fiber and aluminum frame components are very popular materials.

Various sensors are part of the UA. The key flight components are generally combined into an Inertial Measurement Unit (IMU). Critical components of an IMU generally include three axis gyros, accelerometers, electronic compass, and a barometer (altimeter). More advanced drones often include optical flow, linear lidar, or sonar devices to avoid obstacles and assist in take-off and landing.

Integration of an ADS-B IN receiver has also become very popular, as software-defined radios make this very inexpensive and allows the UA to receive the GPS position and velocity of some of the crewed traffic in the area. Note: ADS-B output is required only of some aircraft in certain airspaces and thus it is not a universal solution to be aware of air traffic. Many UAs also incorporate a camera that can be either part of the mission or just an accessory.

The UA also contains 5G user equipment (UE). The UE communicates with GCS over the wireless network. Possible options for 5G enabled UE are commercially available cellular and hotspot devices, Internet of Things (IoT) module and fully integrated 5G modem into a development board.

Finally, a UA must have a computing device to incorporate all the sensor data into the estimated aircraft state, to set the motor speeds, and to communicate with the ground control station.

The diagram in **Figure 5** depicts the hardware architecture of a typical small UA. The flight control processor and mission processor may be a single unit depending on the implementation. The electronic speed control converts speed commands into the necessary voltage signal required to turn the DC brushless motors at the desired speed.

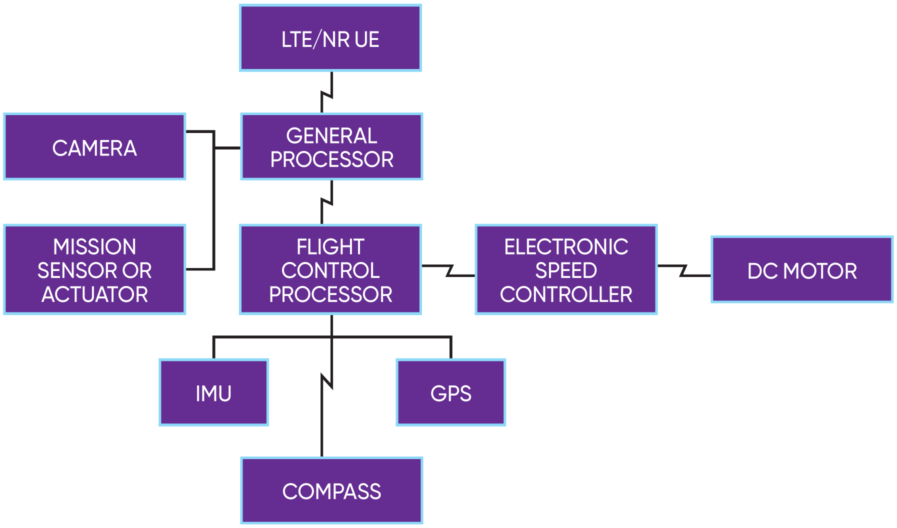


FIGURE 5: TYPICAL UA ARCHITECTURE

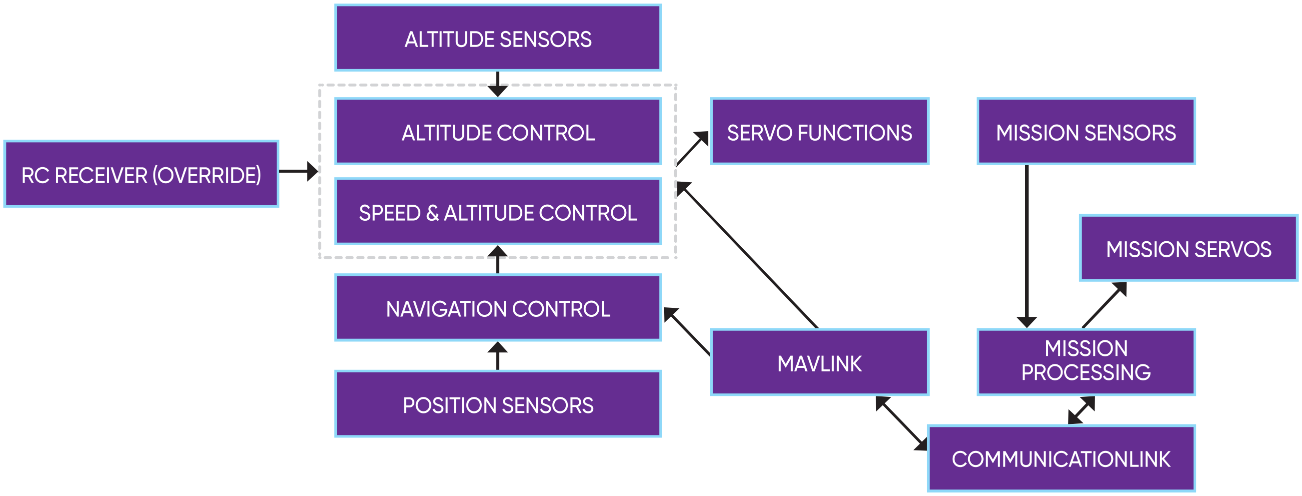


FIGURE 6: UA FUNCTIONAL DIAGRAM

The diagram in **Figure 6** depicts the functional breakout of the UA. MAVLink is an industry-accepted open standard for high-level commands and telemetry for uncrewed aircraft and other vehicle communication. Because MAVLink is extensible, mission commands and telemetry could be implemented within or separately from the MAVLink communications. For Open Generation experiments, a Radio Controlled receiver will be implemented to allow for direct override and control of the drone in the case of failure or other test experiment needs.

5G RADIO ACCESS NETWORK

The 5G Radio Access Network (RAN; a.k.a. next generation radio access network, or NG-RAN) connects the user devices (in this case, unmanned aerial vehicle [UAV]) to the 5G core network. 3GPP specifies the RAN architecture and procedures in TS 38.300 and other specifications. In 5G, 3GPP has defined a RAN functional split (Option 2 split) that splits the Next Generation NodeB (gNB) function into a centralized unit and distributed unit. Other lower-layer splits are left to industry forums. O-RAN Alliance, an industry community that was established as a German entity in 2018, is helping transform RAN into an open, intelligent, virtualized, and fully interoperable RAN. A new lower-layer (intra-PHY) split, called 7-2x, has been standardized by O-RAN Alliance. In additional, other functional elements are introduced and standardized within RAN, allowing it to be open, intelligent, fully interoperable, and capable of supporting verticals; the Open Radio Access Network (O-RAN) architecture is well positioned to support the UAV vertical.

A high-level view of the O-RAN architecture, as defined in “O-RAN.WG1.O-RAN-Architecture-Description-v05.00,” is depicted in **Figure 7** on the next page. It shows the four key interfaces—namely, A1, O1, Open Fronthaul M-plane, and O2—that connect the Service Management and Orchestration (SMO) framework to O-RAN network functions and O-Cloud.

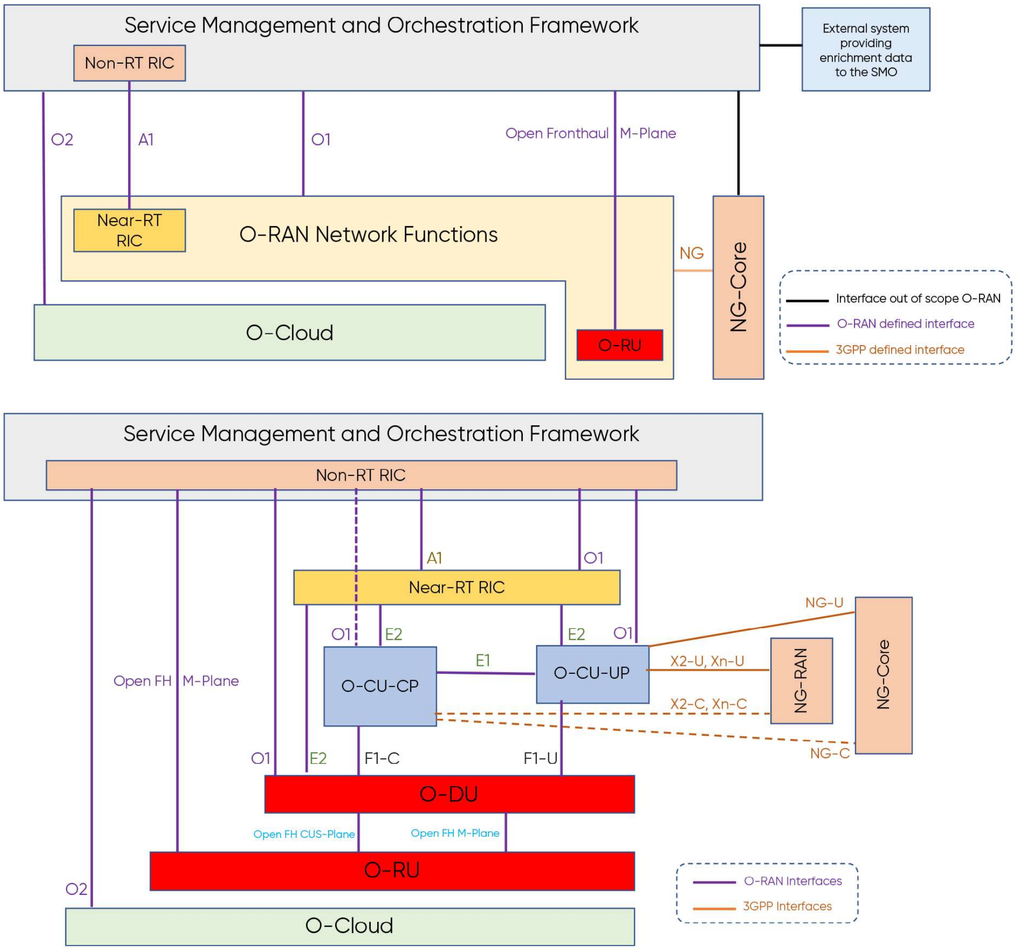


FIGURE 7: O-RAN REFERENCE ARCHITECTURE

Within the logical architecture of O-RAN, the radio side includes Near-Real Time (RT) Radio Intelligent Controller (RIC), O-RAN Central Unit Control Plane (O-CU-CP), O-RAN Central Unit User Plane (O-CU-UP), O-RAN Distributed Unit (O-DU), and O-RAN Radio Unit (O-RU) functions.

Although the O-RAN architecture specifies the O-RAN nodes Near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU as separate entities, it is possible in the implementation to bundle some or all these O-RAN nodes based on use cases and deployment scenarios, and thus collapsing some of the internal interfaces such as F1-c, F1-u, E1, and E2.

Various implementation options are possible; a few are mentioned below:

- Bundle the O-CU-CP and O-CU-UP.
- Bundle the O-CU-CP, O-CU-UP, and O-DU.
- Bundle the Near-RT RIC, O-CU-CP, and O-CU-UP.
- Bundle the O-CU-CP, O-CU-UP, O-DU, and O-RU.
- Bundle the O-DU and O-RU.
- Bundle the Near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU.

Bundling of O-RAN nodes is supported by the O-RAN interfaces O1 and E2. For the O1 interface, the bundled functions will be managed as separate Managed Functions belonging to a single Managed Element. For the E2 interface, the bundled functions can be exposed as part of the E2 Service Model toward the Near-RT RIC. In the implementation options where the Near-RT RIC function is bundled with other O-RAN functions, it may control only E2 Nodes of the same Radio Access Technology (RAT) type (e.g., a bundled near-RT RIC and O-CU-CP may control only E2 Nodes O-CU-UP and O-DU) that are not bundled with Near-RT RIC. Bundling multiple instances of the same type of O-RAN function is supported.

Near-RT RIC Architecture

A high-level view of the RIC architecture is depicted in **Figure 8**.

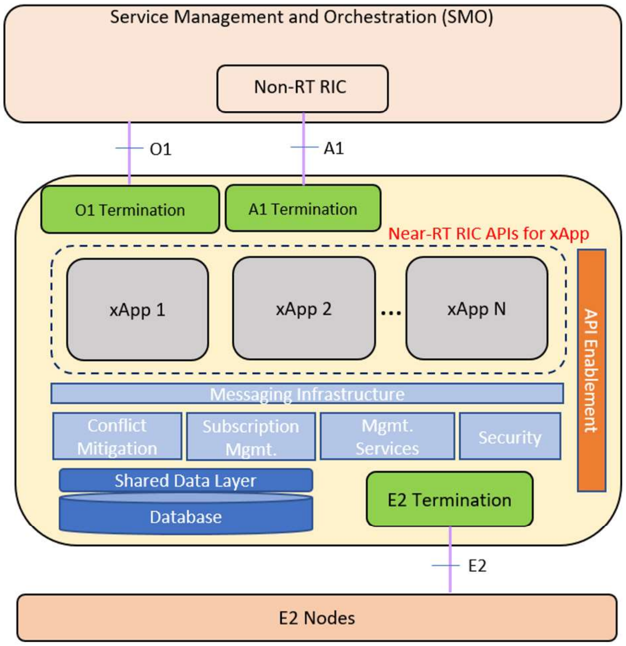


FIGURE 8 NEAR-RT-RIC ARCHITECTURE

The Near-RT RIC hosts the following functions:

- Database, which allows reading and writing of RAN/UE information
- xApp subscription management, which merges subscriptions from different xApps and provides unified data distribution to xApps
- Conflict mitigation, which resolves potentially overlapping or conflicting requests from multiple xApps
- Messaging infrastructure, which enables message interaction among Near-RT RIC internal functions
- Security, which provides the security scheme for xApps
- Management services
- Fault management, configuration management, and performance management as a service producer to SMO
- Life cycle management of xApps
- Logging, tracing, and metrics collection, which captures, monitors, and collects the status of Near-RT RIC internals and can be transferred to an external system for further evaluation
- Interface termination
- E2 termination, which terminates E2 interface from an E2 Node
- A1 termination, which terminates A1 interface from non-RT RIC
- O1 termination, which terminates O1 interface from SMO
- Functions hosted by xApps, which allow services to be executed at Near-RT RIC and outcomes to be sent to E2 Nodes via E2 interface
- Application Programming Interface (API) enablement function supporting capabilities related to Near-RT RIC API operations (API repository/registry, authentication, discovery, generic event subscription, etc.)

Examples of How the O-RAN Defined Functions Can Be Utilized

As mentioned earlier, O-RAN defined RAN architecture is designed with RAN intelligence and verticals in mind. The Near-RT RIC supports specialized radio resource management for specialized applications. Some of the use cases where the RIC (near-RT and non-RT) can be used for dynamic resource allocation are defined below (Reference: O-RAN.WG1.Use-Cases-Analysis-Report-v07.00):

Example:

At higher altitudes, several challenges that lead to a different radio environment are:

- Line of sight (LOS) propagation/uplink interference
- Poor Key Performance Indicator caused by antenna side lobes for base stations
- Sudden drop in signal strength

These challenges directly impact the mobility performance of the drone and the service experience of the user. Dynamically adjusting radio resource allocation policies for the UAV flight path using the RIC helps reduce unnecessary handovers and improves radio resource utilization.

5G CORE NETWORK

Communication for drones makes use of the 5G core network (5GC). There is no special "customization" required for the 5GC to support drones apart from what is specified in 3GPP standards.

The 5G system architecture is defined to support data connectivity and services making use of network function virtualization, software-defined networking, and service-based interfaces for the control plane. Refer to 3GPP TS 23.501 (Section 4.2.3) and TS 23.256 (Section 4.2.3 and Section 4.2.4) for non-roaming and roaming 5GC architecture.

Control Plane Protocol Stack

The control plane carries 5G signaling traffic (as opposed to user traffic). The protocol stack of this communication is briefly described here.

Refer to 3GPP TS 23.501 (Section 8.2) for further information on protocol stack and shown in **Figure 9** and **Figure 10**.

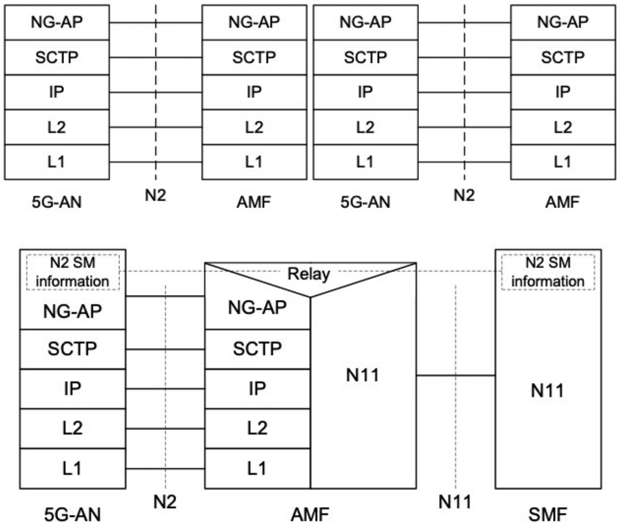


FIGURE 9: 5G ACCESS NETWORK AND AMF

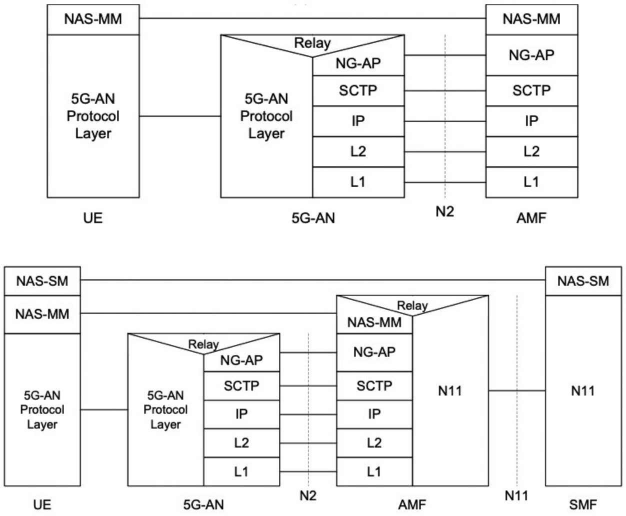


FIGURE 10: CONTROL PLANE BETWEEN UE AND 5GC

NG Application Protocol (NG-AP): This is an application layer protocol between the 5G Access Network (AN) node and the Access and Mobility Function (AMF), defined in TS 38.413.

Stream Control Transmission Protocol: This guarantees delivery of signaling messages between the AMF and 5G-AN node (N2), defined in RFC 4960.

N2 Session Management (SM) information: This is the subset of NG-AP information that AMF transparently relays between the 5G-AN and the Session Management Function (SMF) and is included in the NG-AP messages and N11-related messages.

NAS-MM: The National Airspace System (NAS) protocol for Mobility Management (MM) functionality supports registration management functionality, connection management functionality, and user plane connection activation and deactivation. It is also responsible for the ciphering and integrity protection of NAS signaling. The 5G NAS protocol is defined in TS 24.501 [47].

5G-AN Protocol layer: This set of protocols/layers depends on the 5G-AN. In the case of NG-RAN, the radio protocol between the UE and the NG-RAN node (gNodeB) is specified in TS 38.300 [27].

NAS-SM: The NAS protocol for SM functionality supports user plane Protocol Data Unit (PDU) Session Establishment, modification, and release. It is transferred via the AMF and is transparent to the AMF. The 5G NAS protocol is defined in TS 24.501 [47].

User Plane Protocol Stack

The user plane carries user traffic. The protocol stack of this communication is briefly described here.

Refer to 3GPP TS 23.501 (Section 8.3) for further information on the protocol stack and shown in **Figure 11**.

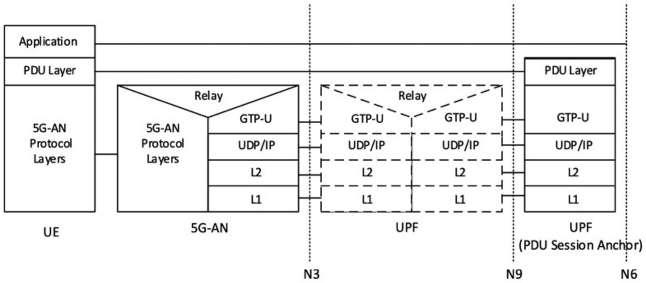


FIGURE 11: USER PLANE BETWEEN UE AND 5GS

PDU layer: This layer corresponds to the PDU carried between the UE and the data network (DN) over the PDU Session. When the PDU Session type is IPv4, Ipv6, or Ipv4v6, it corresponds to Ipv4 packets, Ipv6 packets, or both. When the PDU Session type is Ethernet, it corresponds to Ethernet frames.

GPRS (General Packet Radio Service) Tunnelling Protocol (GTP) for the user plane: This protocol supports tunnelling user data over N3 (i.e., between the 5G-AN node and the User Plane Function [UPF]) and N9 (i.e., between different UPFs of the 5GC) in the backbone network. For details, see TS 29.281 [75]. The GTP shall encapsulate all end user PDUs. It provides encapsulation on a per-PDU Session level. This layer also carries the marking associated with the Quality of Service (QoS) flow defined in Clause 5.7. This protocol is also used on N4 interface, as defined in TS 29.244 [65].

5G-AN protocol stack: When 5G-AN is a 3GPP NG-RAN, these protocols/layers are defined in TS 38.401 [42]. The radio protocol between the UE and the 5G-AN node (gNodeB) is specified in TS 38.300 [27].

User Datagram Protocol/Internet Protocol: These are the backbone network protocols.

5G System and Edge Computing

5G core network architecture allows control and user plane separation and benefits from edge computing. Edge computing is a network architecture concept that enables cloud computing capabilities and service environments, which are deployed close to the UE, and promises several benefits, such as lower latency, higher bandwidth, reduced backhaul traffic, and prospects for new services, compared with cloud environments. Refer to TS 23.558 (Architecture for Enabling Edge Applications) and 3GPP TS 23.548 (5G System Enhancements for Edge Computing) for further information.

The edge computing capabilities supported by 3GPP are illustrated in 3GPP TS 23.558 (Section 4.1). The application layer is a consumer of 3GPP-specified edge computing capabilities.

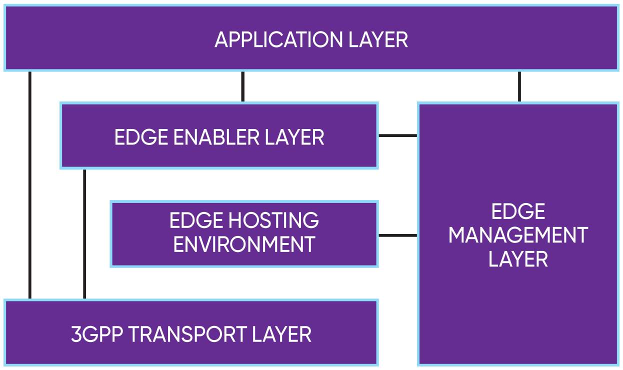


FIGURE 12: OVERVIEW OF 3GPP EDGE COMPUTING

Edge computing enables operator and third-party services to be hosted close to the UE's access point of attachments to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network. 5GS supports the Edge Hosting Environment deployed in the DN beyond the PDU Session Anchor UPF.

Refer to 3GPP TS 23.548 Section 4.2 for the reference architecture representing the relationship between the 5GS and Edge Hosting Environment for non-roaming and Local Break Out roaming scenarios and shown above in **Figure 12**.

MULTI-ACCESS EDGE COMPUTING

Edge computing as an evolution of cloud computing brings application hosting from centralized data centers down to the network edge, closer to consumers and the data generated by applications. Multi-access Edge Computing (MEC) offers application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the 5G network. This environment is characterized by ultra-low latency and high bandwidth as well as real-time access to radio network information that can be leveraged by applications. MEC enables mobile network operators to open their RAN edge to authorized third parties to deploy innovative applications and services flexibly and rapidly toward mobile subscribers, enterprises, and vertical segments including UASs.

The ETSI MEC initiative is an Industry Specification Group (ISG) within ETSI. The purpose of the ISG is to create a standardized, open environment that will allow the efficient and seamless integration of applications from vendors, service providers, and third parties across multi-vendor Multi-access Edge Computing platforms.

Multi-access Edge Computing enables the implementation of MEC applications as software-only entities that run on top of a virtualization infrastructure, which is in or close to the network edge. The Multi-access Edge Computing framework shows the general entities involved. These can be grouped into system-level, host-level, and network-level entities.

Refer to the ETSI GS MEC 003 standard (Section 5) for the MEC architecture framework and shown in **Figure 13**.

Figure 14 shows how the MEC system is deployed in an integrated manner in a 5G network. Refer to ETSI White Paper No. 28 (MEC in 5G Networks – 5G System Architecture and MEC) for more details.

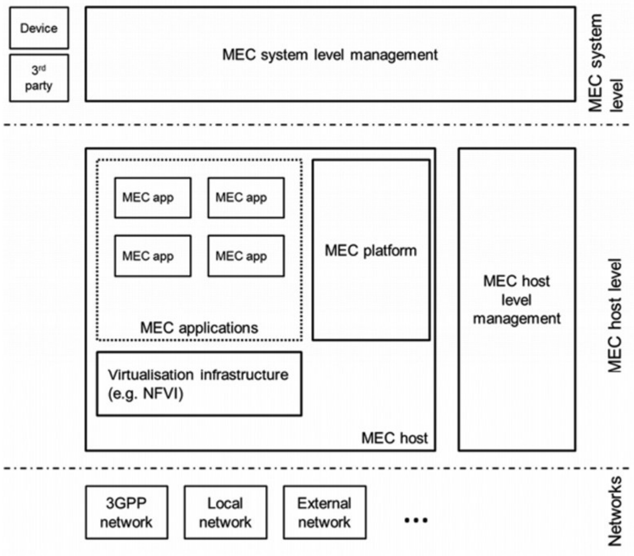


FIGURE 13: MEC ARCHITECTURE

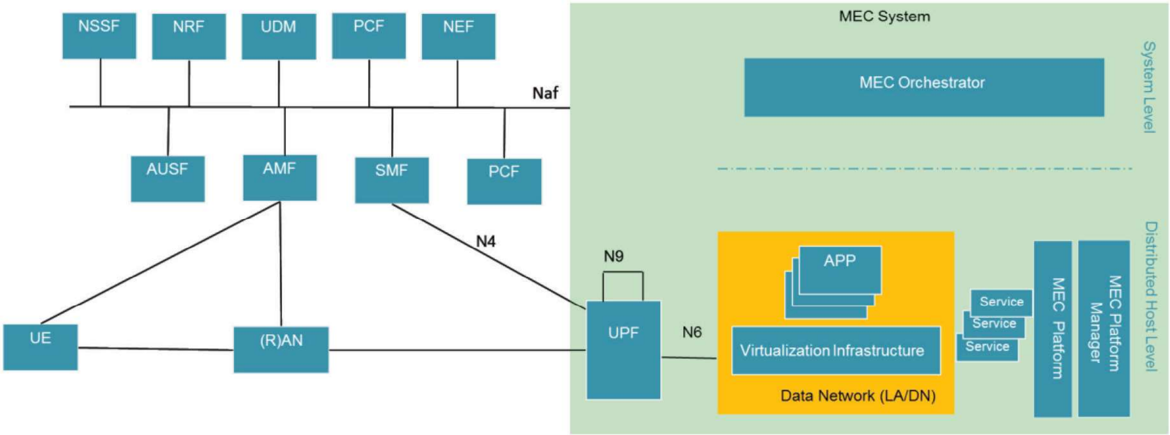


FIGURE 14: 5G SERVICE-BASED ARCHITECTURE AND GENERIC MEC SYSTEM ARCHITECTURE

Network Procedures and Information Flows

UA Registration with 5G Network and USS

A UA needs to register with the 5G network to get authorized to receive services, to enable mobility tracking, and to enable reachability. The UE initiates the registration procedure using one of the registration types (Initial, Mobility update, Periodic update, Emergency) as defined in 3GPP TS 23.502 (Section 4.2.2). 5G Registration includes authentication and authorization, and UE context setup in the network. 3GPP has defined an Authentication and Key Agreement (AKA) protocol and procedures that support user authentication and setup of integrity and confidentiality protection of control plane and user plane data. The 3GPP AKA protocol works on the challenge-and-response authentication protocol based on a symmetric key shared between a user and a network. After the mutual authentication between a user and a home network, keying material is derived to protect further communication between a user and a serving network.

Refer to 3GPP TS 23.256 (Section 5.2.2) for details on the registration procedure in 5GS.

UA PDU Session Establishment with 5G Network

The 5GS supports PDU connectivity service, which provides exchanges of PDUs between a UE and data network identified by a data network name (DNN). The PDU connectivity service is supported via PDU Sessions that are established upon request from the UE.

UAs use PDU Sessions in the UE for connectivity with the USS and for connectivity with a networked UAV controller

A PDU Session can be established when service is needed independently of the UE attachment procedure. The UE can establish multiple PDU Sessions to the same data network or to a different data network over a single or multiple access networks, including 3GPP and non-3GPP at the same time. Each PDU Session supports a single PDU Session type requested by the UE at the establishment of the PDU Session.

Refer to 3GPP TS 23.256 (Section 5.2.3) for details on the PDU Session establishment procedure in 5GS.

Quality of Service

The UA communication may require certain QoS to be satisfied to properly support its application's communication needs.

The 5G QoS model is based on QoS flows and shown below in **Figure 15**. The QoS flow is the finest granularity of QoS differentiation in the PDU Session. One or more Service Data flows can be transported in the same QoS flow if they share the same policy and charging rules. All traffic within the same QoS flow receives the same treatment. A QoS flow may either be Guaranteed Bit Rate (GBR) or Non-GBR depending on its QoS profile. 5G supports Delay-Critical GBR and new concept reflective QoS.

A 5G QoS Identifier (5QI) is a scalar that is used as a reference to 5G QoS characteristics (access node-specific parameters that control QoS forwarding treatment for the QoS flow, such as scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.). Standardized 5QI values are specified for services that are assumed to be frequently used and thus benefit from optimized signaling by using standardized QoS characteristics. Standardized 5QI values have one-to-one mapping to a standardized combination of 5G QoS characteristics, as specified in 3GPP TS 23.501 and Table 5.7.4-1.

QoS Flow Type	QoS Flow Parameters
Non-GBR flow	5QI - 5G QoS Identifier
	ARP - Allocation and Retention Priority
	RQA - Reflective QoS Attribute
GBR flow	5QI - 5G QoS Identifier
	ARP - Allocation and Retention Priority
	RQA - Reflective QoS Attribute
	GFBR - Guranteed Flow Bit Rate
	MFBR - Maximum Flow Bit Rate
	Notification Control
	Maximum Packet Loss Rate

5QI - 5G QoS Identifier
Resource Type - GBR, non-GBR and delay critical GBR
Default Priority Level
PDB - Packet Delay Budget
PER - Packet Error Rate
Default Maximum Data Burst Volume
Default Averaging Window

FIGURE 15: 5G QOS MODEL

Network Requirements

Connection Reliability and Interference Management

CONNECTION RELIABILITY

Cellular networks are designed to serve users on the ground and are highly optimized for this purpose. Base station antennas are typically down tilted to get a good tradeoff between coverage and interference for ground users. Typically, the propagation conditions experienced by users on the ground are different from the propagation conditions experienced by devices/users in the air. Drones flying above rooftops, vegetation, and terrain elevations are more likely to observe radio path clearance to the base stations in the surrounding area. Therefore, they are more likely to experience LOS radio propagation for larger distances, resulting in a higher level of interference from a larger number of surrounding base stations. At the same time, achieving LOS conditions to the serving cell improves the desired signal levels [1].

The experimental results and discussion below use LTE networks, but this is also directly applicable to 5G NR, at least for Frequency Range 1, as both use Orthogonal Frequency Division Multiplexing as air interface technology. Following the UAS study in Release 15, 3GPP introduced measurement reporting enhancements in LTE Release 15. These height-based reporting enhancements are not yet part of 5G NR specifications but are expected to be added later. We note that NR already supports a new measurement event, I1, which is triggered when interference becomes higher than a threshold. However, NR-based specification to support UAV is to be expected in the near future from 3GPP. “NR Support for UAV” was approved as a work item (WI) for Release 18 (RP-213600). It covers:

- Solutions known from LTE (height reporting, flight path reporting, etc.)
- Signaling to support subscription-based aerial UE identification
- Enhancements for UAV identification broadcast
- Study UE capability signaling to indicate UAV beamforming capabilities and, if necessary, Radio Resource Control signaling

Already today, a cellular network designed for terrestrial users using only LTE technology can provide good C2 link reliability for drones. This can be seen from **Figure 16**, which shows the results from measurements of a drone flying in an urban environment during a busy hour at 40 m height while being connected to two live LTE networks. The reliability measure shown is based on the number of packets in uplink and downlink, which are received correctly within 50 ms delay budget at the application layer. Details can be found in [2]. The LTE networks (operator 1 and operator 2), even though not being optimized for users in the air, can deliver high reliabilities (88.5% and 98.5%). Several techniques can be used to improve the reliability for the C2 link, like interference coordination, and the use of advanced receivers with interference cancellation and beamforming from the UAV and potentially from the network side. All these techniques have been shown to improve the reliability of the C2 link for airborne drones [3]. As an example, the requirement of 99.9% reliability for the C2 link can be achieved with a simple enhancement: connecting to both networks simultaneously and sending the data packets over each of them leads to a reliability of 99.99%, as shown in **Figure 16** under the label "Dual LTE." This packet duplication scheme can also be implemented within one network through Packet Data Convergence Protocol duplication, where packets can be transmitted simultaneously to and from different cells within the same cellular network. Although the observations are for LTE, they are equally applicable to 5G NR, especially with LTE-NR dual connectivity. We note that this dual connectivity framework requires two transmitter/receiver (TX/RX) chains, which is not feasible in many scenarios. The new Release 18 WI enhances support for UAV in 5G NR and does not rely on dual connectivity or the need for multiple TX/RX chains.

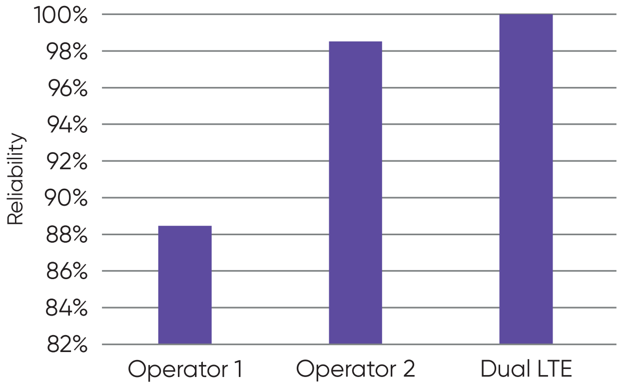


FIGURE 16: C2 RELIABILITY OF A DRONE—COMPARISON CHART

COEXISTENCE WITH TERRESTRIAL USERS

Applications on drones often generate a lot of uplink data (e.g., video), leading to high uplink data rates. Combining this with the fact that an airborne drone sees many more cells than does a terrestrial device leads to the fact that a drone can cause significant uplink interference [4].

An example of this type of measurement is shown in **Figure 17**, where the increase of interference due to a user being at 100 meters in the air compared with being on the ground, while uploading data in a rural area, is shown for the 20 most interfered cells. The figure shows that the interference increase is significant, up to 8 dB, and the eight most interfered cells see four times more interference when it is caused by a user at 100-meter height compared with being on the ground with the same traffic.

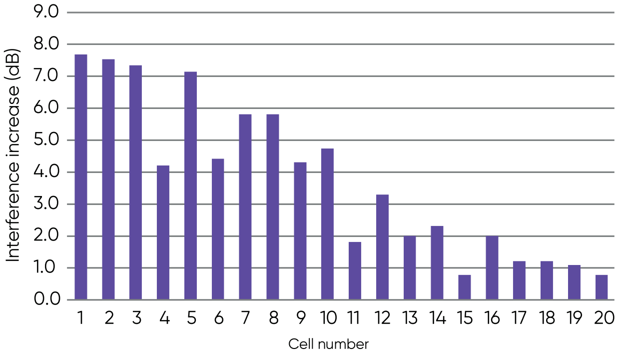


FIGURE 17: INTERFERENCE IMPACT TO TERRESTRIAL USER BY AN AERIAL USER AT 100 MM HEIGHT

This high interference to many neighboring cells can cause coexistence issues, leading to a lower throughput for the users on the ground being served by these interfered cells.

One solution is to lower the output power of the user in the air (uplink power control), which is one of the mechanisms introduced for drones in the Release 15 LTE specifications. This will, however, also lower the potential throughput of the aerial user, which might be undesirable.

Another solution is illustrated in **Figure 18** using an example of a special scenario. In this scenario, a large group of people together at an event (e.g., a concert or a sports match) is depicted. This large group of users may use a lot of upload capacity from the network (e.g., uploading

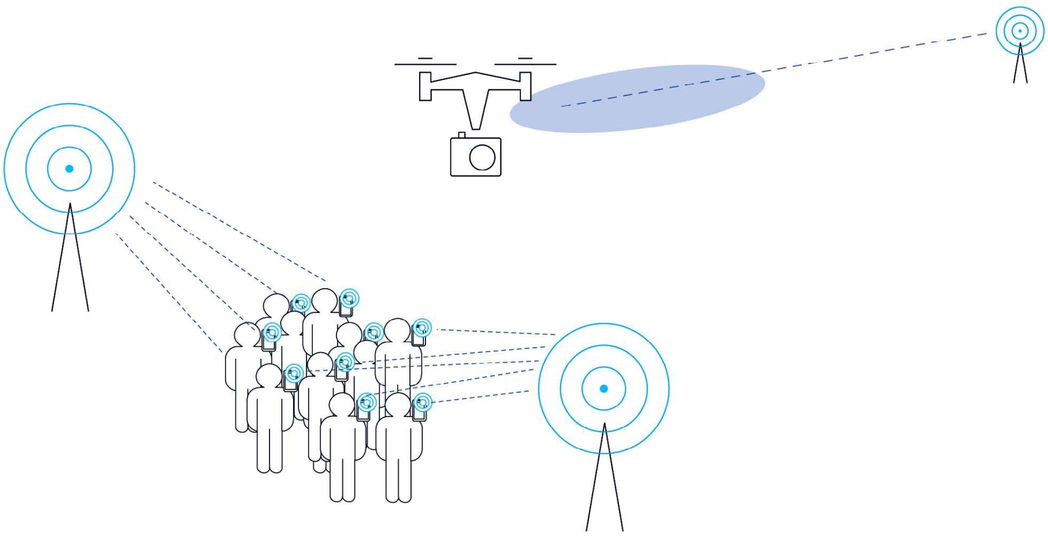


FIGURE 18: BEAMFORMING UAV SIGNAL AND STEERING INTERFERENCE AWAY FROM A LARGE GROUP OF USERS

pictures from the event). A camera drone is live streaming the event. If this drone is using an omnidirectional antenna, it will interfere with the cells to which all the users on the ground are connected, thereby interfering with their uploads. However, using a directional beam from the drone and pointing it to a cell farther away from the location of the event will provide more resources for the streaming drone and at the same time avoid interfering with the users on the ground.

INTERFERENCE MANAGEMENT SCHEMES

Different techniques aiming at coping with increased interference levels and providing UAV connectivity have been proposed in the literature. As mentioned above, efforts up until now have been directed toward LTE networks, and likely the LTE techniques will be mimicked for NR in Release 19 of 3GPP standards.

Massive multiple input multiple output (MIMO) with 3D beamforming capabilities assumed at the base stations is proposed in [5], [6], and [7], among other solutions. By pointing the beams toward the flying UAVs, the potential communication link can be strengthened, while other cellular links may observe reduced interference as the beams are pointed in different directions. Interference coordination among multiple cells is proposed in [8]. The work in [9] further extends the concept of interference mitigation and investigates the possible UAV assistance in the process. Similarly, null steering can be used at gNB to improve uplink quality. Although all the mentioned solutions show the potential for serving a future flying UAV, they may require hardware changes to the network side. This, especially in the early deployment phase, when only a limited number of UAVs are expected, may be costly and not profitable. Furthermore, when the number of flying UAVs increases, UAV flight requirements may impose large investment requirements in the cellular networks.

Technique	Gain Potential	Complexity Drone	Complexity Network
UAV Beamforming	●	◑	○
Interference Cancellation	◔	◑	○
Power Control	◑	○	◔
Interference Coordination	●	○	◑

TABLE 1: COMPARISON OF THE INTERFERENCE MITIGATION TECHNIQUES FOR DRONES

Table 1 summarizes the various interference mitigation techniques for drones for gain potential and drone/network complexity point of view.

Positioning

ARCHITECTURE AND DIFFERENT POSITIONING METHODS

3GPP TS 38.305 defines the positioning architecture and interfaces relevant for positioning, as shown in **Figure 19**. The standard enables positioning using both control plane signaling with 3GPP-defined interfaces and user plane signaling. The key components are the location server or Location Management Function (LMF) and the NG-RAN. The LMF receives measurements and assistance information from the NG-RAN and the UE, via the AMF over the NL interface, and it uses them to compute the position of the UE. 3GPP further defines two protocols for NR positioning: (1) the LTE positioning protocol (LPP), which defines the signaling and procedures between the LMF and the UE; and (2) the New Radio positioning protocol "a" (NRPPa), which defines the signaling and procedures between the LMF and the NG-RAN. LPP is defined in 3GPP TS 37.355, and NRPPa is defined in 3GPP TS 38.455.

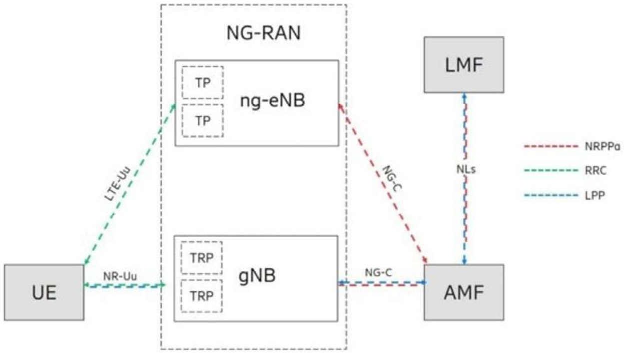


FIGURE 19: 5G POSITIONING SUPPORT ARCHITECTURE

To enable more accurate positioning measurements than LTE, new reference signals were added to the NR specifications in Release 16. These signals are the NR positioning reference signal (PRS) in the downlink and the sounding reference signal for positioning in the uplink. PRS is specifically designed to deliver the highest possible levels of accuracy, coverage, and interference avoidance and suppression. To increase positioning accuracy over LTE positioning methods, round-trip time (RTT) and angle-based positioning methods are also included in 5G NR.

The NR standard defines both RAT-dependent (i.e., NR based) and RAT-independent positioning methods. These methods can be supported in a UE-based mode where the UE calculates the location or in a UE-assisted mode where the LMF calculates the location. **Table 2** shows the various methods that are supported by the NR standard.

Method	UE Based	UE Assisted, LMF Based	NG-RAN Node Assisted	Secure User Plane Location (SUPL)
A-GNSS	Yes	Yes	No	Yes
OTDOA Note 1, Note 2	No	Yes	No	Yes
E-CID Note 3, Note 4	No	Yes	Yes	Yes, for E-UTRA
Sensor	Yes	Yes	No	No
WLAN	Yes	Yes	No	Yes
Bluetooth	No	Yes	No	No
TBS Note 5	Yes	Yes	No	Yes (MBS)
DL-TDOA	Yes	Yes	No	Yes
DL-AoD	Yes	Yes	No	Yes
Multi-RTT	No	Yes	Yes	Yes
NR E-CID	No	Yes	Yes	Yes (DL NR E-CID)
UL-TDOA	No	No	Yes	Yes
UL-AoA	No	No	Yes	Yes
NOTE 1: This includes TBS positioning based on PRS signals. NOTE 2: In this version of the specification, only OTDOA based on LTE signals is supported. NOTE 3: This includes Cell ID for NR method when UE is served by gNB. NOTE 4: Enhanced Cell ID based on LTE signals. NOTE 5: In this version of the specification, only for TBS positioning based on MBS signals.				

TABLE 2: POSITIONING PERFORMANCE REQUIREMENTS

The NR RAT-dependent positioning techniques are:

- NR-Enhanced Cell ID Methods
- Multi-Round Trip Time Positioning
- Downlink Angle-of-Departure
- Downlink Time Difference of Arrival
- Uplink Time Difference of Arrival
- Uplink Angle-of-Arrival

In the next sections, the requirements for positioning (e.g., in terms of accuracy) are examined as they emerged from the use cases that 3GPP considered.

OUTDOOR POSITIONING REQUIREMENTS

As mentioned above, dedicated 5G positioning reference signals, measurements, and procedures were introduced in 3GPP Release 16. Before that, positioning accuracy and requirements in 3GPP had traditionally been defined to address regulatory requirements related to emergency call locations. As an important industrial use cases for positioning, UAV positioning requirements are proposed in

Scenario	Accuracy (95% confidence level)		Availability	Corresponding Positioning Service Level in TS 22.261	UE Speed	Latency for Position Estimation of UE
	Horizontal Accuracy	Vertical Accuracy				
8K video live broadcast	[0.5 m]	[1 m]	99%	5	[<120 km/h]	1s
Laser mapping/ HD patrol	[0.5 m]	[1 m]	99%	5	[<120 km/h]	1s
4*4K AI surveillance	[0.1 m]				[<60 km/h]	
Remote UAV controller through HD video	[0.5 m]	[1 m]	99%	5	[<120 km/h]	1s
Periodic still photos	[0.1 m]	[1 m]			[<60 km/h]	

NOTE 1: The column on "Corresponding Positioning Service Level in 3GPP TS 22.261" maps the scenarios listed in Table 3 to the service levels defined in 3GPP TS 22.261.

NOTE 2: The positioning accuracy in this table is not related to navigation or safety.

TABLE 3: TYPICAL SCENARIOS AND POSITIONING REQUIREMENTS (REPRODUCED FROM TABLE 7.3-1 IN 3GPP TS 22.125)

Release 17 of NR. **Table 3** lists typical scenarios and the corresponding high positioning requirements for horizontal and vertical accuracy, availability, heading, latency, and UE speed, as defined in 3GPP TS 22.125, Clause 7.3.

INDOOR POSITIONING REQUIREMENTS

Indoor positioning use cases are also addressed by NR and 3GPP positioning. Use cases specific to factories of the future or the Industrial IoT have been the major focus of positioning enhancements of 3GPP Release 17. Details of the particular use cases and evaluated scenarios can be found in TR 38.857, with the detailed requirements for positioning defined in 3GPP TS 22.104. The requirements set by 3GPP for NR-based positioning in Industrial IoT use cases are:

- Horizontal position accuracy (<0.2 m) for 90% of UEs
- Vertical position accuracy (<1 m) for 90% of UEs
- End-to-end latency for position estimation of UE (<100 ms, of the order of 10 ms is desired)
- Physical layer latency for position estimation of UE (<10 ms)

These requirements were set to ensure that use cases, like robots moving on a factory floor and asset tracking within a factory, could be met. Future releases of 3GPP are expected to push the requirements even further; one such use case could be drone indoor inspection, which may require tighter vertical positioning accuracy requirements. We note that positioning methods to achieve these accuracies are still being developed.

Detect and Avoid

Detect and avoid requirements are currently under development as the FAA works to adopt standards that will provide a means of compliance to fly BVLOS. Currently, the two primary DAA published standards are RTCA DO 365B and ASTM F3442/F3442M-20, each of which takes a different but complementary approach.

The RTCA standard starts with identifying the two surveillance types needed to support DAA (e.g., cooperative and noncooperative) and the sensors that compose them. It then provides architecture alternatives that combine various subcomponents

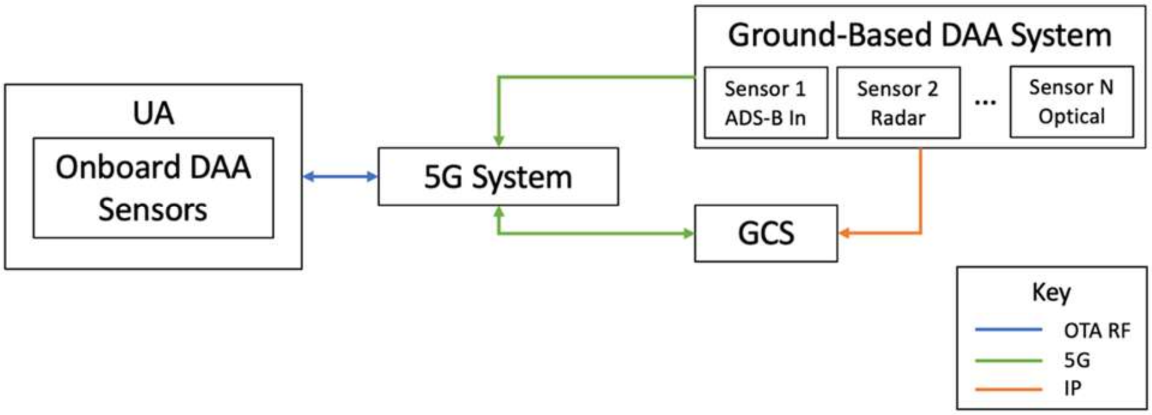


FIGURE 20: UAS AND 5G REFERENCE ARCHITECTURE WITH DAA

to achieve sufficient DAA.

The limitations of the current RTCA standard are its scope and its specificity. This standard does not apply to small UASs operating below 400 feet, but rather focuses on integrating UASs into other portions of the NAS, where they will frequently interact with crewed aircraft. It also restricts possible DAA solutions that may achieve performance without conforming to one of the RTCA-proposed architectures.

The ASTM standard is architecture agnostic, instead focusing on performance-based DAA requirements. The limitation of this standard is again scope, with the requirements being solely for separation of the UA and crewed aircraft, not UA-UA or other obstacle avoidance.

Regardless of the standard, certain DAA elements will be common among use cases. Both noncooperative traffic (e.g., another UA unable to share position and identity information) and cooperative traffic (e.g., helicopters with ADS-B Out) can be detected with ground-based surveillance. Outdoor use cases may need an onboard noncooperative surveillance sensor unless an adequate network of ground-based sensors is available.

The primary DAA concerns for the current Open Generation use cases, excluding Indoor Inspection and Security, are low-flying helicopters (e.g., police, medevac, news) and other UAs. Most helicopters operating in large cities are equipped with ADS-B Out and can be detected by ADS-B In receivers (or other cooperative traffic sensors). Noncooperative sensors, such as optical/acoustic sensors and radars, will be used to detect other UAs or noncooperative traffic.

While ideally a self-contained onboard DAA system would have the benefits of being fully independent and portable, the technology is not widely available at this point. More than likely, the first drones to obtain an Airworthiness Certificate will use at least some elements of ground-based detection of aircraft and obstacles (e.g., an onboard noncooperative sensor and ADS-B In sensors placed throughout a city).

Onboard sensors may not require any 5G systems. However, any ground-based systems will need to convey their traffic information to either the UA or GCS, depending on where the avoidance algorithm is handled. **Figure 20** proposes a high-level flow of DAA information from ground-based DAA system to GCS and GCS to UA over a 5G network. Here, the 5G system is providing transport for the DAA information and does not make use of any 5G system features.

Surveillance information used for DAA should also be validated. A single-source DAA solution becomes problematic when that source fails. Position information shared by another aircraft can be incorrect because, for example, sensors may fail. In the future, 5G may be able to provide another solution, such as "validation by multiliterate."

Remote Identification

OVERVIEW

The FAA describes Remote ID as the ability of a drone in flight to provide identification and location information that can be received by other parties, and says that the Remote ID helps the FAA, law enforcement, and other federal agencies find the control station when a drone appears to be flying in an unsafe manner or where it is not allowed to fly.

Remote ID allows governmental and civil identification of UASs for safety, security, and compliance purposes. The objective is to increase UAS remote pilot accountability by removing anonymity while preserving operational privacy for remote pilots, businesses, and their customers. Remote ID is an enabler of enhanced operations such as BVLOS operations as well as operations over people.

The FAA's Notice of Proposed Rulemaking on Remote Identification of Uncrewed Aircraft Systems, which was published on December 31, 2019, included the "Limited Remote Identification UAS" category to transmit remote ID messages through an internet connection to a Remote ID USS.

In the FAA Final Rule (Part 89), the "Limited Remote ID UAS" was eliminated and replaced with Remote ID Broadcast Module requirements to enable existing UAs to comply. Though this resulted in the elimination of the network-based or internet transmission requirements in the Final Rule, the use of Network Remote ID is not precluded in future FAA regulations. Jay Merkle, Executive Director of the FAA's UAS Integration Office, has stated:

"The Network Remote ID has a role to play in these UTM development endeavors, and the FAA is committed to working with the drone community to continue to explore how network information sharing can support safe integration activities. Though not required by regulation, operators can share information using a network connection today, and we encourage this. Robust information sharing today may provide operational insight that may be leveraged in the future."

3GPP STANDARDS

Support of Network Remote ID

3GPP TS 23.256 defines the Stage 2 specifications for enhancements of the 5G system to support UASs. The specification includes the support of:

- UAV Remote Identification based on aviation industry regulations
- Control plane solution for:
  - UAV authentication and authorization for the support of Remote ID
  - UAV-USS connectivity

3GPP Support of Broadcast Remote ID

A RAN WI proposal for Release 18 (RP-213600) on enhancing NR support for UAVs includes ground identification using PC5, specifically to support drone identification in system information for broadcast and groupcast but not unicast.

ASTM STANDARDS

ASTM Standard F3411 covers the performance requirements for Remote ID of UASs and was designed to be applicable to UASs that operate at low altitude over diverse environments regardless of airspace class. F3411 defines message formats, transmission methods, and minimum performance standards for two forms of Remote ID: broadcast and network.

Broadcast Remote ID is based on the transmission of radio signals directly from a UAS to receivers in the UAS's vicinity. The Remote ID rule requires that the UA broadcast ID messages can be received by commonly available UE. This has resulted in F3411-19 concentrating on the use of Bluetooth and Wi-Fi over an unlicensed spectrum. However, the standard is not strictly limited to these technologies, so it is possible that future 3GPP standards could meet the Remote ID broadcast ID requirements and be accepted by the FAA as a means of compliance with the rule.

Network Remote ID is based on communication by means of the internet from a network Remote ID service provider that interfaces directly or indirectly with the UAS, or with other sources in the case of non-equipped network participants.

F3411-19 is currently in the process of being updated with changes required to accommodate the final FAA rule on Remote ID. As previously stated, this rule does not require a network solution. However, this option has not been removed from future FAA rulemaking, and the updated F3411 standard will still include the network Remote ID requirements.

Proximity Services and PC5 Sidelink

3GPP-defined Proximity Services (ProSe) have relevance to the UAS communication, as will be described herein.

3GPP introduced ProSe, sometimes referred to as "Device-to-Device" (D2D) communications, in LTE starting with Release 12. This introduced a new D2D interface called PC5 primarily to support Mission Critical services in Release 12 and 13 and Vehicular-to-Everything (a.k.a. V2X) communications in Release 14 and Release 15. 5G NR introduced a Proximity Services definition and a 5G NR PC5 sidelink in Release 16.

3GPP TS23.304 specifies 5G ProSe including support for ProSe Direct Discovery, ProSe Direct Communications, and UE-to-Network Relay.

PC5 is an interface between two ProSe-enabled UEs and supports D2D communication between such UEs. In the context of the UAS, the UAV may encompass a ProSe-enabled UE. The PC5 link will allow support for Broadcast RID for drone identification in UASs.

The 5G NR PC5 sidelink supports unicast, sidelink groupcast, and sidelink broadcast.

5G ProSe Direct Discovery allows a ProSe-enabled UE to discover other 5G ProSe-enabled UEs in its vicinity based on direct radio transmissions between the two UEs using NR sidelink.

The ProSe feature allows direct communication between two or more ProSe-enabled UEs that are in proximity using NR, without requiring a base station.

The 5G ProSe feature also supports Indirect Network Communication where a ProSe-enabled UE can act as a relay between the network (i.e., a 5G base station) and another ProSe-enabled UE that is out of range of the network. The 5G ProSe service supports a Network Application Server (formerly ProSe Function) that can provide services to a ProSe-enabled UE.

3GPP TR 23.755 Release 17 studied application layer support for UASs and UTM and will include support for communications between UAVs, which will leverage ProSe features and use of sidelink for DAA and other UAS requirements.

Advanced Use Cases

Package Delivery

USE CASE DESCRIPTION AND REQUIREMENTS

Several commercial, service-oriented companies are interested in using UASs to increase product distribution, reduce product delivery times, and achieve corresponding potential cost savings. Commercial package delivery in this context means the delivery segment of a package to its destination (i.e., the last mile). Delivery can be directly to a recipient's desired/selected location from the point of origin or distribution centers (fixed or mobile). These delivery locations may be in urban, suburban, and rural areas. The standards and regulatory framework supporting UAS capabilities need to evolve before such operations can become a reality and ubiquitous. **Figure 21** provides a pictorial overview of the use case and **Table 4** lists data communication requirements for this use case.

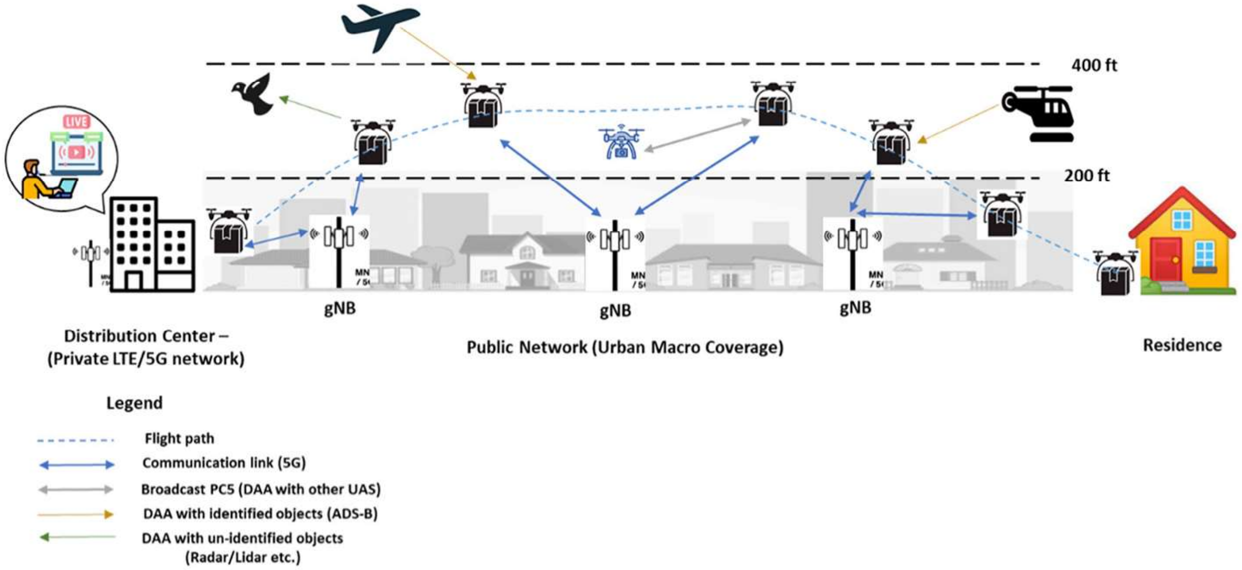


FIGURE 21: OVERVIEW OF PACKAGE DELIVERY USE CASE

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	C2	High	500 ms	10^{-5}	35 Kbps
Non-Critical Communication	Navigation	Medium	1 second	10^{-5}	35 Kbps
Mission Payload	Image Delivery	Medium	500 ms	10^{-3}	1 Mbps
Critical Communication	DAA (UA to UA) – PC5 Sidelink	High	100 ms	10^{-5}	35 Kbps
Critical Communication	DAA (Manned Aircraft to UA)	High	1 second	10^{-6}	35 Kbps

TABLE 4: PACKAGE DELIVERY: DATA COMMUNICATION REQUIREMENTS

UNCREWED AIRCRAFT CONSIDERATIONS

Various organizations have designed and deployed experimental UAs for the purpose of package delivery. The UA has a few specific and challenging requirements:

- The ability to carry a payload package. Early designs have focused on payloads of about 5 to 10 pounds.
- Vertical take-off and landing capability is considered desirable depending on the delivery mechanism.
- Appropriate range. Aircraft range is a key parameter to the usefulness of the aircraft. A UA that is capable of flying only extremely short distances with little reserve power has limited utility. A typical use case for a drone delivery flight is from a local warehouse to a residential location. Thus, a range of about 10 miles would likely provide sufficient capability to reach many customers with reserve power.
- A DAA system that can avoid collision with other aircraft as well as obstacles and terrain.
- A safety system that allows flight over human beings as needed.
- A navigation system capable of remaining in the desired airspace and remaining clear of known obstacles.
- Approved aviation lighting is required for the aircraft to fly between sunset and sunrise.
- An Airworthiness Certificate from the FAA showing the aircraft is safe for the intended operation.

To meet these requirements, most applicants for an Airworthiness Certificate from the FAA have arrived at a hybrid design between a rotorcraft and an airplane. The rotorcraft allows for the vertical take-off and landing capability, while the airplane mode allows for a greatly increased range.

Most current UAs employ electric motors and LiPo batteries. However, for higher-endurance and heavy payload capability, some drones use piston petroleum or hydrogen engines. The initial Open Generation experiments will use electric motor systems.

Interaction with a USS is currently required only for flight in controlled airspace but may be desired for the additional services provided.

5G NETWORK SUPPORT

A UA must register with the 5G network and get authorized to receive services, to enable mobility tracking and to enable reachability. 5G Registration includes authentication and authorization, and UE context setup in the network. 5G Registration optionally includes authentication and authorization with a UA with the USS for supporting UAS connectivity, identification, and tracking.

The 5GS supports a PDU connectivity service, which provides exchanges of PDUs (i.e., data frames) between a UE and data network identified by a DNN. The PDU connectivity service is supported via PDU Sessions that are established upon request from the UE. A UA shall use PDU Sessions in the UE for connectivity with a networked UA-Controller, the USS, and mission-specific application servers after a UA has been authenticated and authorized by the 5G network and optionally the USS.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Service
5	Non-GBR	10	100 ms	10^{-6}	Critical and Non-Critical Drone Communication (C2 and Navigation), DAA (Manned Aircraft to UA)
8	Non-GBR	80	300 ms	10^{-6}	Mission Payload (Image Delivery)

TABLE 5: 5QI VALUES FOR PACKAGE DELIVERY USE CASE

Registration and PDU Session establishment procedures are well defined in 3GPP TS 23.501 and 3GPP TS 23.256, and are referenced in this document.

The PDU Session for this use case will contain multiple QoS flows; each QoS flow characteristic is defined with standard 5QI values. An example mapping of 5QI values that fulfill the traffic requirements is presented in **Table 5**. It is worth noting that the 5QIs that fulfill the requirements present a much lower delay budget than expected by use case requirements.

Emergency Response (Hazmat Incident)

USE CASE DESCRIPTION AND REQUIREMENTS

Drones can play an important role in providing first responders with aerial views from the area where a hazmat incident has occurred, for increased situational awareness. One example might be a fuel truck involved in a highway accident that results in fuel spillage and/or a localized fire. Traffic on the highway may already be blocked or encountering heavy delays, slowing the arrival of emergency vehicles on the scene. Drones can be deployed quickly and much faster and much closer than can ground vehicles for an initial assessment, without further endangering people to the incident. In such a situation, drones could transmit high-quality video as well as data from other sensors. Access to such data would help assess the severity of the incident and optimize resources to be dispatched at the scene. **Figure 22** provides a pictorial overview of the use case and **Table 6** lists data communication requirements for this use case.

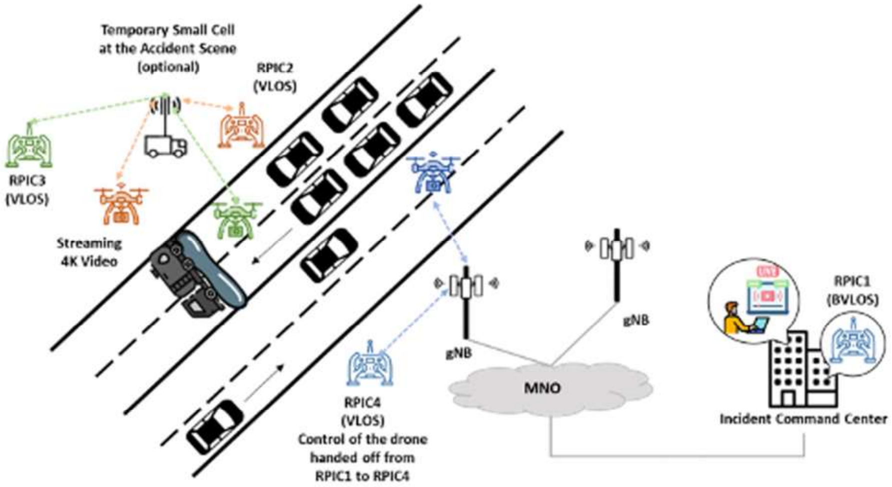


FIGURE 22: OVERVIEW OF EMERGENCY RESPONSE USE CASE

5G Network

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	C2 (waypoints based)	High	500 ms	10^{-5}	35 Kbps
Critical Communication	C2 (direct stick steering)	High	40 ms	10^{-5}	35 Kbps
Critical Communication	C2 Video (aid BVLOS)	High	140 ms	10^{-5}	4–9 Mbps
Mission Payload	4K or 8K Live Video	High	20 ms	10^{-5}	50–100 Mbps

Broadcast

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	DAA (UA to UA)	High	100 ms	10^{-5}	35 Kbps

TABLE 6: EMERGENCY RESPONSE: DATA COMMUNICATION REQUIREMENTS

UNCREWED AIRCRAFT CONSIDERATIONS

This use case has very similar requirements to the package delivery use case, with the following exceptions:

- There is typically no need to "deliver" a payload to the response site; however, this could be a possible capability.
- Real-time video quality requirements may be significantly higher for first responders to assess the situation accurately.
- Additional sensors, such as a smoke detector or a Geiger counter, may be included to evaluate harmful situations.
- Aircraft range could be short for small UASs deployed at the scene but may need to be much farther for UAs that are deployed from a central location and that are intended to cover a large geographic area.

5G NETWORK SUPPORT

A UA must register with the 5G network and get authorized to receive services, to enable mobility tracking and to enable reachability.
5G Registration includes authentication, security establishment, and UE context setup in the network. 5G Registration optionally includes authentication and authorization with a UA with the USS for supporting UAS connectivity, identification, and tracking.

The 5GS supports PDU connectivity service, which provides exchanges of PDUs between a UE and data network identified by a DNN. The PDU connectivity service is supported via PDU Sessions that are established upon request from the UE. A UA uses PDU Sessions for connectivity with a networked UA-Controller, the USS, and mission-specific application servers after a UA has been authenticated and authorized by the 5G network and optionally the USS.

UE registration and PDU Session establishment procedures are well defined in 3GPP TS 23.501 and 3GPP TS 23.256, and are referenced in this document.

The PDU Session for this use case will contain multiple QoS flows; each QoS flow characteristic is defined with standard 5QI values. An example mapping of 5QI values that fulfill the traffic requirements is presented in **Table 7**. It is worth noting that the 5QIs that fulfill the requirements present a much lower delay budget than expected by use case requirements.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Service
5	Non-GBR	10	100 ms	10^{-6}	C2 (Waypoint Based, Video), Mission Payload (4k/8k Video)
80	Non-GBR	68	10 ms	10^{-6}	C2 (Direct Stick Steering), Mission Payload (Camera Control)

TABLE 7: 5QI VALUES FOR EMERGENCY RESPONSE USE CASE

Indoor Inspection and Security

USE CASE DESCRIPTION AND REQUIREMENTS

Drones are used indoors to fly programmatically defined missions within warehouses and other large indoor spaces. The missions traverse pre-determined routes or visit waypoints to collect images in real time and/or stream video for indoor inspections, warehouse inventory, or indoor security, where a drone's ability to follow a path and provide real-time video uplink is central to the use case. **Figure 23** provides a pictorial overview of the use case and **Table 8** lists data communication requirements for this use case.

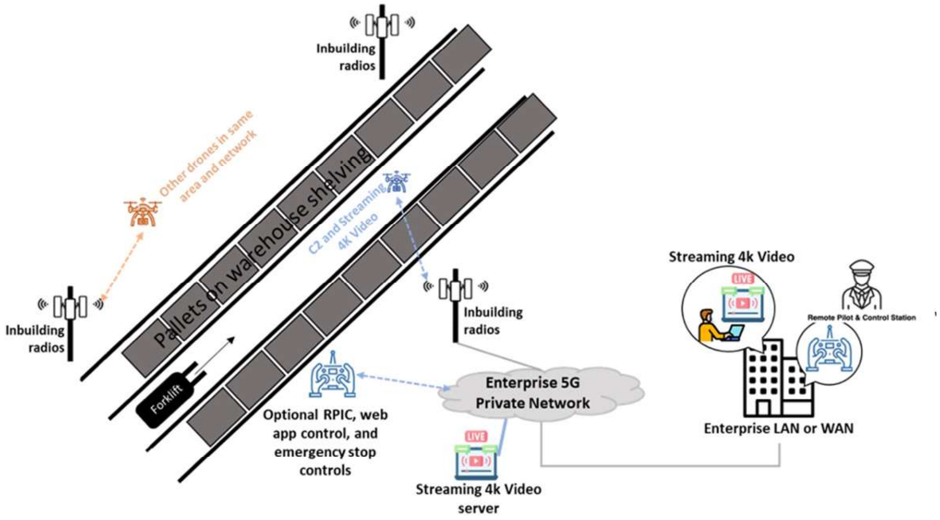


FIGURE 23: OVERVIEW OF INDOOR INSPECTION AND SECURITY USE CASE

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	C2	High	500 ms	10^{-5}	35 kbps
Non-Critical Communication	Navigation (map updates and real-time intervention)	Medium	100 ms	10^{-4}	100 kbps
Mission Payload	4K Videos or Image Delivery	Best Effort	360 ms	10^{-3}	25 Mbps

TABLE 8: INDOOR INSPECTION AND SECURITY: DATA COMMUNICATION REQUIREMENTS

UNCREWED AIRCRAFT CONSIDERATIONS

Indoor drone use is often in very tight spaces and thus likely requires a much smaller drone. The aircraft range can also be very limited if it must return to a charging location. Indoor navigation needs to be significantly more accurate and generally cannot rely on GNSS. Video requirements can range from a simple bar code scanner to high-resolution video depending on the implementation.

5G NETWORK SUPPORT

A UA must register with the 5G network and get authorized to receive services, to enable mobility tracking and to enable reachability. 5G Registration includes authentication, authorization, and UE context setup in the network.

The 5GS supports PDU connectivity service, which provides exchanges of PDUs between a UE and data network identified by a DNN. The PDU connectivity service is supported via PDU Sessions that are established upon request from the UE. A UA uses PDU Sessions for connectivity with a networked UA-Controller, and mission-specific application servers after a UA has been authenticated and authorized by the 5G network.

UE registration and PDU Session establishment procedures are well defined in 3GPP TS 23.501 and 3GPP TS 23.256, and are referenced in this document.

The PDU Session for this use case will contain multiple QoS flows; each QoS flow characteristic is defined with standard 5QI values. An example mapping of 5QI values that fulfill the communication performance requirements is presented in **Table 9**. It is worth noting that the 5QIs that fulfill the requirements present a much lower delay budget than expected by use case requirements.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Service
5	Non-GBR	10	100 ms	10^{-6}	Critical and Non-Critical Drone Communication (C2 and Navigation)
8	Non-GBR	80	300 ms	10^{-6}	Mission Payload (Video and Image Delivery)

TABLE 9: 5QI VALUES FOR INDOOR INSPECTION AND SECURITY USE CASE

Static Infrastructure Inspection

USE CASE DESCRIPTION AND REQUIREMENTS

For an electrical distribution substation inspection scenario, there is a fixed geographic footprint for each substation, which is likely serviceable by at least a single cell. The physical dimensions of an electrical substation can vary, but for this scenario it is assumed the facility covers approximately 7 acres, or a square of about 550 feet per side. Access to the substation is controlled, and therefore ground risk is more easily mitigated, making the safety case for remote BVLOS operations easier. "America's Energy Future: Technology and Transformation" (2009) states that there are 60,000 distribution substations in the United States' energy grid. **Figure 24** provides a pictorial overview of the use case and **Table 10** lists data communication requirements for this use case.

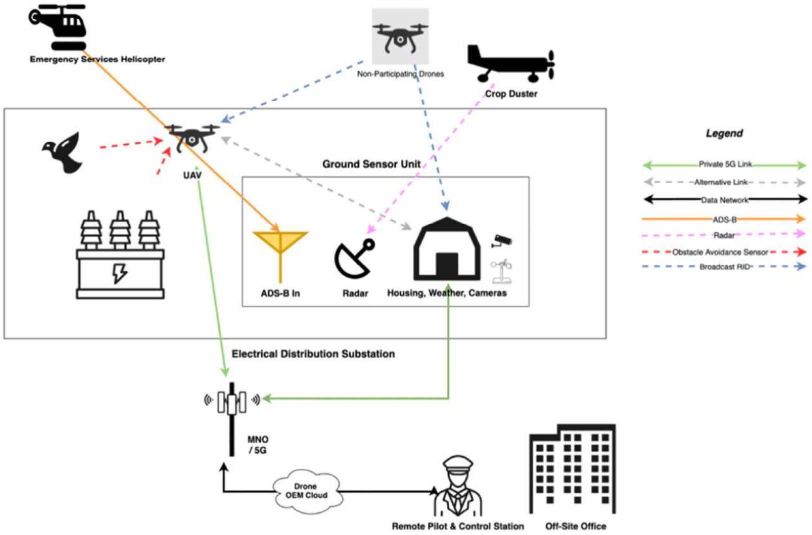


FIGURE 24: OVERVIEW OF STATIC INFRASTRUCTURE INSPECTION USE CASE

5G Network

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	C2 (Waypoint Based)	High	500 ms	10^{-5}	35 kbps
Non-Critical Communication		Medium	500 ms	10^{-3}	35 kbps
Mission Payload and Imagery	4K Video	Best Effort	100 ms	10^{-5}	25 Mbps

Broadcast

Data Type	Service	Priority Level	Packet Delay Budget	Packet Error Rate	Throughput
Critical Communication	DAA (UA to UA)	High	100 ms	10^{-5}	35 kbps
	DAA (Manned Aircraft to UA)	High	1 second	10^{-6}	35 kbps

TABLE 10: STATIC INFRASTRUCTURE AND INSPECTION: DATA COMMUNICATION REQUIREMENTS

UNCREWED AIRCRAFT CONSIDERATIONS

This use case is also very similar to the package delivery requirements, with the following modifications:

- Aircraft range does not need to be as large, but flight endurance could still be a factor depending on the time required to conduct the inspection.
- DAA may not be required for some cases where either visual observers or the pilot can maintain visual line of sight with the aircraft.
- High-resolution video is nearly always required, as video is typically the output of the inspection sensor located on the drone.

5G NETWORK SUPPORT

A UA must register with the 5G network and get authorized to receive services, to enable mobility tracking and to enable reachability. 5G Registration includes authentication, authorization, and UE context setup in the network. 5G Registration optionally includes authentication and authorization with a UA with the USS for supporting UAS connectivity, identification, and tracking.

The 5GS supports PDU connectivity service, which provides exchanges of PDUs between a UE and data network identified by a DNN. The PDU connectivity service is supported via PDU Sessions that are established upon request from the UE. A UA uses PDU Sessions for connectivity with a networked UA-Controller, the USS, and mission-specific application servers, after a UA has been authenticated and authorized by the 5G network and optionally the USS.

UE registration and PDU Session establishment procedures are well defined in 3GPP TS 23.501 and 3GPP TS 23.256, and are referenced in this document.

The PDU Session for this use case will contain multiple QoS flows; each QoS flow characteristic is defined with standard 5QI values. An example mapping of 5QI values that fulfill the traffic requirements is presented in **Table 11**. It is worth noting that the 5QIs that fulfill the requirements present a much lower delay budget than expected by use case requirements.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Service
5	Non-GBR	10	100 ms	10^{-6}	Critical Communication (Waypoint Based); Non-Critical Communication; Mission Payload (4K Video)

TABLE 11: 5QI VALUES FOR STATIC INFRASTRUCTURE INSPECTION USE CASE

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