ATIS-I-0000060

Unmanned Aerial Vehicle (UAV) Utilization of Cellular Services

Enabling Scalable and Safe Operation

Abstract

This whitepaper addresses how mobile cellular networks can support the adoption of Unmanned Aerial Vehicles (UAVs) as well as provide services that can help address areas of concern in a convenient and technically feasible way. This whitepaper shows how the synergy and effective use of the combination of UAVs and mobile cellular services technologies will offer mutual benefits.

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1. Introduction

In the last few years, the application of new technology has vastly improved the performance and accessibility of Unmanned Aerial Vehicles (UAVs). The UAV market is soaring, not just for hobbyists but increasingly for a range of professional and civil applications (see Figure 1).

The increased use of UAVs is proving valuable for recreational and professional purposes. However, it is also raising concerns about safety, security, and privacy. This paper shows:

- How mobile cellular networks can support the adoption of UAVs as well as provide services that can help address areas of concern in a convenient and technically feasible way.
- That the synergy and effective use of the combination of UAVs and mobile cellular services technologies will offer mutual benefits.

Figure 1 – Example UAV Applications

2. Cellular Services in Support of UAVs

Prior to the recent transformation of the UAV landscape, most UAVs were model aircraft flown by hobbyists. These used simple radio control technology on dedicated channels to allow the pilot to use a handheld controller to remotely move the flight control surfaces on the UAV.

In contrast, modern UAVs require much more sophisticated communication between the UAV and the ground. Factors driving the need for more advanced communications include:

- Increased numbers of UAVs meaning that the use of dedicated point-to-point radio channels between the UAV and the ground is no longer efficient.
- The need for high-speed digital data transmission to support modern piloting systems and to support the collection of digital data (e.g., real-time video) from the UAV.
- Increased range of UAV operation (including interest in beyond line-of-sight operation) meaning that point-to-point radio between the UAV and the pilot is not always efficient.
- Requirements to ensure safe and managed operation of UAVs, including management of airspace, that in turn require reliable communications to the UAV at all stages of flight.

For UAVs operating at low altitude (<400 feet), mobile cellular technology has excellent characteristics to address the communication needs of UAVs. Strengths of cellular technology include:

- Already installed wide coverage area, including all major population centers, both nationally and internationally.
- High reliability and managed Quality of Service (QoS) ensured by use of operator-controlled licensed spectrum.
- Robust security including projection against eavesdropping and tampering with communications.
- Seamless mobility across the entire cellular coverage area.
- High capacity with the ability to absorb the impact of a rapidly growing UAV population.
- Integrated location technology to complement Global Positioning System (GPS) and other location systems.

- Continuous technical evolution and investment in developing and deploying new technologies to enhance system performance.
- Massive economies of scale through global technical alignment.
- Proven track record of support for an open, interoperable, multi-vendor ecosystem in both the network and for devices/user equipment.

Several studies have already shown (e.g., [2]) that existing cellular networks can perform well as a platform for UAV communications. Existing cellular networks can meet important objectives in terms of delivering predictable and reliable communications to UAVs.

In the following sections, this report discusses in more detail the requirements for low-altitude UAV communications and the role of cellular networks in addressing these requirements.

3. Cellular Communication for Command and Control, Regulation and Safe Operation

The communications between a UAV and the ground can be separated into the "command and control" aspects which relate to the safe control and operation of the UAV itself and the "payload" aspects which relate to facilities being carried by the UAV as part of its mission (see Figure 2).

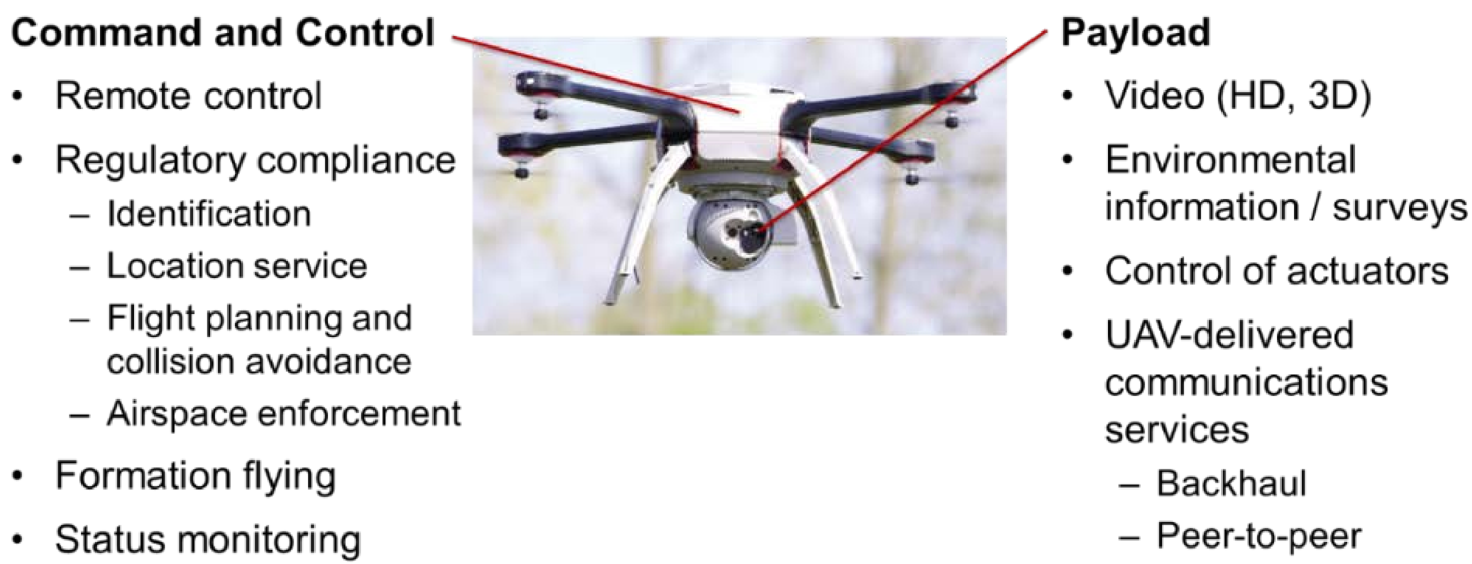

Figure 2 – Command and Control, and Payload Communications

Fulfilling the command and control needs of the UAV is critical to successful UAV operation and vital to addressing regulatory compliance aspects. This section discusses the requirements in the command and control area and how cellular may address these requirements.

Cellular Support for UAV Control

An obvious requirement for UAVs is the ability for the pilot to control their position and orientation. For UAVs without a fixed-flight plan this control will involve the pilot directing the UAV in real-time from a remote-control console. In other cases, the UAV may have a pre-set flight plan (e.g., in terms of a sequence of GPS waypoints to hit) and can largely operate autonomously. However, even in this case the ability for a pilot to interrupt the stored flight plan and take back real-time control is needed to deal with unexpected eventualities.

Control operations require a communications interface between the UAV and the pilot's location. Requirements on this interface include:

- Reliable transmission of pilot commands to the UAV and return of telemetry data from the UAV to the pilot.
- Low latency to support real-time piloting of the UAV.
- Sufficient capacity to serve all UAVs within an area.
- Sufficient coverage/range to communicate with the UAV throughout its flight.
- Resistance to unintentional and malicious interference from natural and man-made sources.
- Fail-safe operation in the event of failure of the original link.

Two leading technologies for this control interface are Wi-Fi (and similar technologies in unlicensed spectrum) and Cellular. The following table compares these technologies in terms of these requirements.

Table 1 – Comparison of Wi-Fi and Cellular Technologies Pertaining to Control Operation Requirements

Requirement	Wi-Fi	Cellular
Reliable transmission	In uncongested spectrum, Wi-Fi can provide reliable transmission. However, congestion in unlicensed spectrum can degrade the service, leading to interruptions in data delivery.	Operating in licensed spectrum with a managed allocation of resources, the cellular system is able to prioritize resources for particular applications to improve reliability. As cellular operates in licensed spectrum, this should be free from congestion caused by other unmanaged users.
Low latency	Wi-Fi can manage latency through QoS management tools, but the achievable latency depends on the level of congestion in the unlicensed spectrum.	Cellular provides QoS tools supported by resource management algorithms to provide assurances of latency for traffic.
Capacity for all UAVs	Within an area, the capacity of Wi-Fi is often limited by interference from other users of unlicensed spectrum.	Cellular has a planned capacity with its coverage area.
Coverage/range	Unless some type of "mesh" networking is used, the range of Wi-Fi is limited to the maximum range obtained between the UAV and a station located near the pilot.	Cellular handover allows the range of communication to be extended to anywhere within the coverage area of the cellular network.

Requirement	Wi-Fi	Cellular
Resistance to interference	Wi-Fi is designed to permit multiple users to independently operate in the same spectrum with minimal interference.	Cellular operates in licensed spectrum which should be free from interference from unmanaged users. If cellular communication to one base-station is degraded due to interference, then a handover may be performed to a different base-station with better radio conditions.
Fail-safe operation	In the event of loss of the Wi-Fi link (e.g., if the UAV goes beyond the operating range of the link), the communications will be lost until the link conditions change and communications can be re-established.	If cellular communication to one base-station is degraded or lost, then a handover may be performed to a different base-station with better radio conditions.

Current regulations in the U.S. normally require UAVs to be flown within the line-of-sight of the operator. Improvements in command and control technology, including communication aspects, may in the future mean that operation beyond the line-of-sight of the operator is permitted. This would improve the economics and flexibility in the use of UAVs for some commercial applications.

Support of Regulatory Requirements and Safe Operation

Increased usage of UAVs has given an impetus to regulatory and voluntary mechanisms to ensure safe operation during flights. Initially, the regulatory environment is based heavily on processes that require manual human intervention to ensure observance (e.g., the FAA's Small Unmanned Aircraft System (sUAS) Registration Service). Even for these systems, the use of cellular and other wireless communications technologies can be advantageous. For example, the FAA B4UFLY smartphone app (https://www.faa.gov/uas/where_to_fly/b4ufly/) uses cellular data services and GPS to enable UAV operators to get accurate and up-to-date information about UAV operating requirements.

While wireless communications are useful in the current environment, the goal of regulators and the industry is to introduce electronic systems that use real-time data to help promote safe UAV operation. This is being studied as part of the NASA Unmanned Aircraft System (UAS) Traffic Management (UTM) initiative [1]. The UTM work initially focuses on UAVs operating in Class G (uncontrolled Airspace) but envisages evolution to other types of airspace.

For small UAVs, the UTM's stated goals include:

- Only authenticated UAVs and operators are allowed to operate in the airspace.
- UAVs stay clear of each other.
- UAVs and manned aviation stay clear of each other.
- UAVs, their operators or support systems have awareness of all constraints in the air-space and of people, animals or structures on the ground and UAVs will stay clear of them.
- Public safety UAVs should be given priority over other UAVs and manned aviation.

The figure below depicts the general architecture for the proposed UTM system (in UTM terminology, a UAV is called a UAS). An important aspect is the exchange of real-time information between the UAS Service Supplier (USS) Network and the UAS Operators. The UTM model is based on the premise that UAVs can provide real-time telemetry about their location and operating conditions and respond in real-time to changes in the operating constraints.

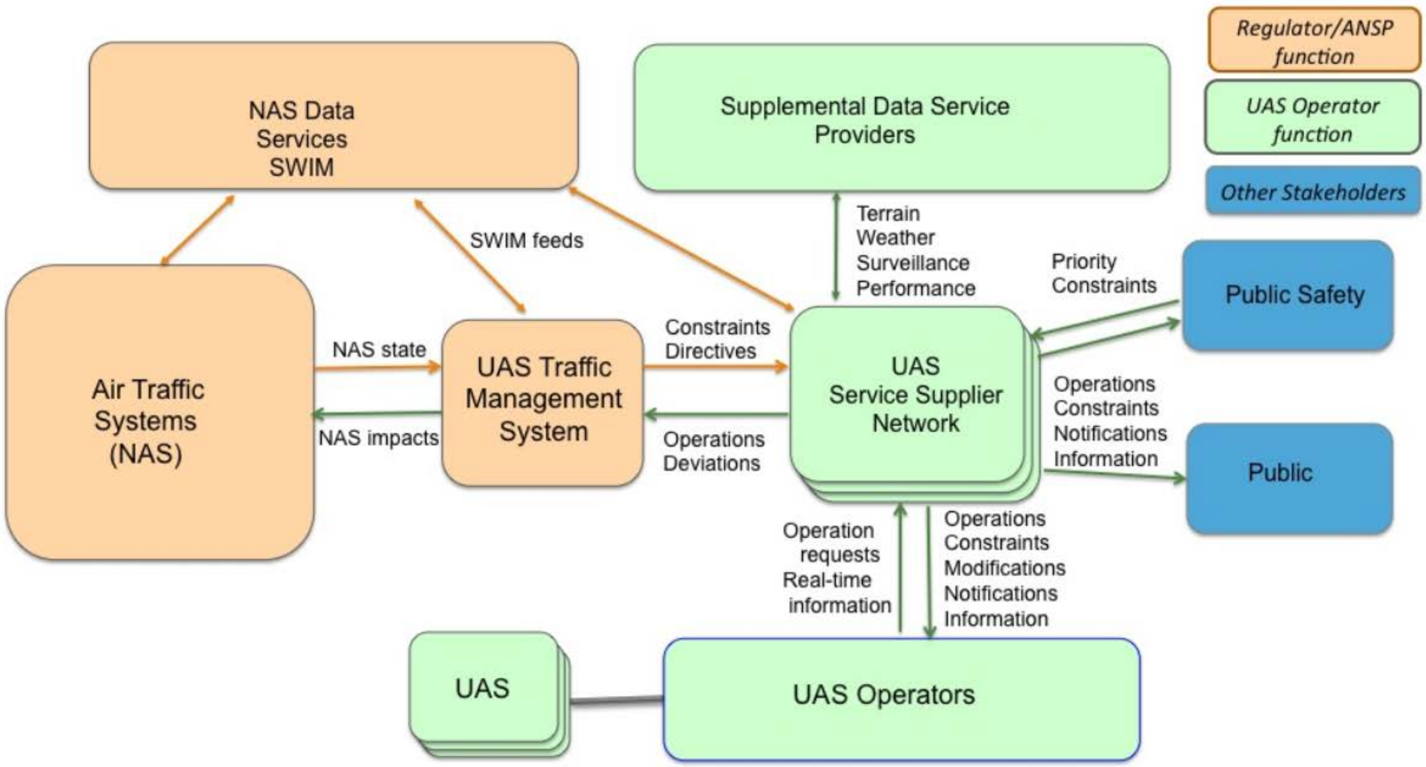

Figure 3 – Proposed Architecture of UTM (from [1])

Within this architecture, cellular communications are particularly relevant to two key interfaces:

- Between the UAS operator and the UAS to allow communication during flights
- Between the USS and the UAS operator to allow the operator to communicate in real-time when it is away from accessible, wired Internet services

In this model, the communication between the USS and the UAS takes place via the UAS operator. An alternative architecture would be to have the UAS communicate with the USS directly. This would also be an interface where cellular communications would be an advantageous choice in many scenarios.

Recognizing that much of the UAV operation takes place from temporary or movable sites, the need to provide wireless communication from the operator to the infrastructure is just as important as the need to support wireless services between the operator and the UAV.

In section 2.1, the characteristics and advantages of cellular communications for UAV control applications are addressed. These are equally applicable in meeting the communication requirements of the UTM model shown above.

4. Location Services for UAVs

UAV Location Requirements

UAV location services are important for Navigation, air traffic control (e.g., UTM) and regulatory compliance. To assess the location technology options, it is important to understand the UAV location requirements. The requirements include:

- Location accuracy requirements – x, y & z.
- Location update rates.
- Real-time navigation and reporting requirements.
- Availability in areas of need.
- Performance in various environments (rural, suburban, urban, dense urban, indoors).
- Reliability and availability of signal.
- Redundancy.
- Receiver cost and mass market availability.

Location Technologies

UAVs will intrinsically have many innate location technologies as proven by the market today (e.g., Standalone GPS, Sensors). Having access to a cellular network provides new location technologies (that UAVs can potentially leverage) and signaling for existing location technologies. The following subsections provide a brief Pro and Con overview of several positioning technologies enabled in 3GPP that can be used to provide location services. Since many 2G and 3G networks are being phased out, this document will focus on positioning technologies for 4G LTE. LTE cellular networks use the LTE Positioning Protocol (LPP) to support location services. As of Release 13, LPP supports the following positioning technologies: Assisted Global Navigation Satellite System (A-GNSS; Including GPS, Galileo, GLONASS, BDS), Observed Time Difference of Arrival (OTDOA), Enhanced Cell ID (E-CID), Terrestrial/Metropolitan Beacon Systems (TBS/MBS), Wireless Local Area Network (WLAN), and Bluetooth. In addition, Uplink Time Difference of Arrival (UTDOA) is also defined for LTE, but is not widely deployed.

One issue to consider for positioning technologies for UAVs is if the location is calculated in the device (standalone or User Equipment [UE]-based) or at a location server (UE-assisted). The choice of standalone, UE-based or UE-assisted location technologies has different implications depending on the purpose for which the derived location information is being used. These implications are discussed in later sections.

NOTE: In this document, the terms "UE-based" and "UE-assisted" are used to align with terminology in 3GPP and other places. In the context of UAVs, the term "UE" refers to the communications module that is part of the UAV. In standalone mode, no assistance data is required to be sent from the network location server to the UE.

A-GNSS

Pros: A-GPS is commonly deployed. Standalone, UE-based and UE-assisted positioning are supported. Provides very accurate location including altitude (<5 meters error) in open sky conditions and usable in urban and dense urban environments with some diminished accuracy and reliability. Latest devices support multiple GNSS constellations (e.g., GPS, GLONASS, Galileo) which can overcome poor satellite geometry, outages, and individual Space Vehicle (SV) failure for any one constellation. Underlying constellations are managed systems for high reliability. Used in aviation for decades. Real Time

Kinematics (RTK) and Precise Point Positioning (PPP) variants of GPS and GNSS can achieve sub-meter accuracy in open sky environments. RTK will be included in Release 15.

Cons: Multipath in urban and dense urban environments leads to increased position errors and/or availability issues. Concerns about local jamming, including from illegal, but commonly available, jamming and spoofing devices.

NOTE: There is an increased awareness of the risks associated with systemic reliance on A-GNSS.

OTDOA

Pros: Typically deployed in areas with LTE and supporting VoLTE. Healthy 3GPP Roadmap including Release 14 enhancements for higher accuracy. UE-based OTDOA has been agreed for development in Release 15 which may overcome latency issues for UE-assisted OTDOA. Underlying cellular networks are managed systems for high reliability.

Cons: No accurate altitude capability. Accuracy issues in urban and dense urban environments. Performance for UAVs under study in 3GPP – for instance, increased inter-cell interference for airborne receivers. UE-assisted only would create latency for navigation. The Positioning Reference Signal (PRS) uses a small portion of revenue-generating LTE spectrum.

E-CID (Enhanced-Cell ID)

Pros: Commonly deployed. Underlying cellular networks are managed systems for high reliability.

Cons: Low precision, suitable only for "general area" of flight. No accurate altitude capability. Lack of UE-based would create latency for navigation.

WLAN

Pros: Common receiver. Can operate independently of GPS. Enables some altitude determination if the altitude of the AP is known due to limited range (e.g., receiving a WLAN signal means a UE is normally within around 50 meters of the Access Point [AP]).

Cons: Coverage limited, performance variable, not reliable (power outage scenario). Performance in outdoor open sky conditions unknown. UAV may use Wi-Fi for command, control, and/or data. Crowded unlicensed spectrum. Unlikely usability for a UAV unless flying close to or within a building structure. Typically, WLAN is not part of a managed system, which can limit reliability.

Bluetooth

Pros: Commonly available receiver.

Cons: UE-assisted only. Short range, not reliable, works indoors.

Terrestrial Beacon Systems (TBS)/Metropolitan Beacon Systems (MBS)

NOTE: The MBS Interface Control Document (ICD) includes both beacon details as well as barometric pressure data transmitted in the beacons themselves and assumes that pressure sensors are embedded in the UE.

Pros: Wide area coverage including suburban, urban, and dense urban canyons, high precision 3D geolocation in Standalone and UE-based modes. In UE-assisted mode, the Enhanced-Serving Mobile Location Centre (E-SMLC) would need to request barometric pressure measurements via the LTE Positioning Protocol (LPP) to determine high-precision 3-D location. MBS can be operated to meet mission-critical reliability requirements. Can operate independently of GPS. Can maintain good performance in multipath/Non-Line of Sight (NLOS) signal environments. May complement GNSS, including common Application Specific Integrated Circuit (ASIC) integration. Underlying location network managed for high reliability.

Cons: Not widely deployed.

Inertial Sensors

Pros: Able to accurately maintain 3D location for varying periods (e.g., up to 5 minutes for Microelectromechanical systems [MEMS]-based accelerometers) while other positioning methods (e.g., GPS) are unavailable. To be included by 3GPP in Release 15. May provide an estimate of instantaneous velocity, acceleration, and used in aviation for roll, pitch, heading, and navigation.

Cons: MEMS-based inertial sensors can accumulate errors more rapidly with time than other types.

Barometric Sensors

Pros: Able to accurately determine change in altitude and absolute altitude if atmospheric pressure is available for a nearby reference station. Primary altitude determination method for general aviation, and present in nearly every manned aircraft. Supported by 3GPP in Release 14 for standalone, UE-assisted, and UE-based positioning modes.

Cons: May not be accurate if accurate reference information is unavailable. MEMS-based implementations have varying accuracy.

Cellular Location Services for UAV Navigation

GPS is commonly used for UAV navigation today; however, GPS performance can be affected in urban and dense urban environments, where the weak satellite signals can be blocked by buildings and multipath reflections impact the position accuracy. In addition, there are concerns on GPS outage, jamming, and spoofing, therefore a backup system to GPS is required in all areas.

Several location services considered above can provide a supplement to GPS for navigation. This will require location information to be available at the UAV. In the case of UE-based and standalone location modes this naturally occurs. In the case of UE-assisted location modes the location must be transmitted from the network to the UAV. Because of the latency involved with transmitting UE-assisted location calculations, and the loss of location services in the event of a loss of network coverage, UE-based or standalone modes will likely be preferred for UAV navigation. UE-based modes will require network assistance data, so only standalone modes are truly independent of network connectivity.

A likely outcome for UAVs will be the combination of several different location solutions to improve both performance and reliability. For example, the Barometric Sensors solution might be combined with OTDOA or ECID to ensure more accurate 3D location. Similarly, Inertial Sensors might be combined with A-GNSS to mitigate reduced visibility of Space Vehicles (SVs) caused by a dense urban environment.

Cellular Location Services for Assurance of Regulatory Compliance

For regulatory compliance, UAVs need to be kept out of restricted airspace, and may need to periodically report their position. As with navigation, cellular location services can be used to supplement GPS positioning. Either UE-based or UE-assisted approaches could be used, as latency will not be as important as for navigation. In the case of a UE-based approach, the UAV must transmit the calculated location to a ground-based authority if centralized recording of UAV locations is required. The location server could forward the location to an external party.

In the context of assuring regulatory compliance, the use of UE-based location services implies the need for a high degree of trust in the UE located on the UAV. If the UE is tampered with or is flown in an area where spoof Global Navigation Satellite System (GNSS) signals are being transmitted, then the location reported by the UE may be inaccurate. For UE-based location services used for regulatory compliance purposes, it is recommended that suitable methods to secure the UE against tampering are employed.

The use of UE-assisted location-finding technology can be more resistant to tampering, as the location server that performs the location calculations is not subject to the risk of tampering by end-users and can be managed by a trusted entity such as a mobile network operator.

Another mechanism that can be used to add tamper-resistance to location services is to record and correlate location data that is independently derived using different location technologies. Faking corresponding location data for more than one technology is potentially a much harder task than jamming or spoofing a single technology.

UAVs may be required to log airspace violations. A flight plan often includes geofencing boundaries and the UAV could be required to log when a geofence has been breached. This logging would preferably occur even while the UAV is out of communication with the UAV operator. These logs could be downloaded later for transmission to the FAA. Note that violations of flight plans are not necessarily only positional, but could include violation of file flight parameters such as rate of climb/descent, turning radius, etc.

5. Enhancing the Effectiveness of Cellular for UAVs

3GPP Roadmap of Features for UAV Support

Standards developed by 3GPP are the technical basis for almost all mobile cellular systems currently operating. Therefore, it is essential that 3GPP addresses the requirements for UAVs in its work.

In the short term, UAV operation will take place on existing networks using LTE technology. Therefore, an initial focus of 3GPP should be to address the use of LTE for UAV applications. 3GPP is also developing 5G standards using the "new radio" (NR) interface. Requirements and experience established in LTE should be extended into 5G and NR so that these technologies also provide a strong platform for UAVs.

Development of features with applicability to UAVs will be spread over several releases. The following table shows how UAV-related requirements and solutions are developing in 3GPP releases.

Table 2 – 3GPP Roadmap for UAV-Related Requirements and Solutions

3GPP Release	UAV-Related Requirements and Solutions
Release 14	- Introduction of requirements for LTE Mission Critical Data. - High-level requirements for 5G defined.
Release 15	- Study item on UAVs agreed. - Ensure that LTE bearers meets the appropriate requirements for Command and Control (reliability, throughput, latency, etc.). - Ensure that the LTE bearers for payloads (e.g., high definition video) meets the appropriate requirements (reliability, throughput, latency). - Ensure that UAVs do not cause excessive disruption of ground-based LTE users. - Meet any regulatory requirements for UAV communications.
Release 16 (projected content – not yet agreed)	- Apply LTE lessons to NR. - Ensure that LTE/NR positioning technologies can be integrated into the UAV sensor suite. - Ensure that LTE/NR Proximity Services (ProSE) services can be used for direct UAV-to-UAV communication. - Ensure that LTE/NR supported identities are applicable to UAV identification requirements.

3GPP Requirements on UAVs

Requirements that are relevant to UAV applications can be found in two 3GPP specifications:

3GPP TS22.282 ("Mission Critical Data services over LTE") includes the following requirements:

- Altitude: up to 150m.
- Prioritization: Telemetry data can be prioritized and prevented from pre-emption.
- Identity: Traffic will be identifiable.
- 3GPP TS22.261 ("Service Requirements for the 5G System") makes specific mention of UAVs and includes the following requirements:
- More accurate positioning that also includes direction and velocity.
- Flexible prioritization of UAV communications.
- Ultra-secure communications.

Cellular Radio Propagation, Interference Mitigation, and Handover for UAVs

Existing cellular networks are designed to serve hand-held user equipment that is either at ground-level or is carried into fixed vertical structures such as tall buildings. UEs that are attached to UAVs (and thus operate at altitude) experience different propagation effects to hand-held UEs. This, in turn, impacts aspects such as the radio performance, interference, and handover.

Industry players have already shown that existing networks can support UAV operation, and have studied them though field trials and modelling the radio performance of cellular traffic to UAVs [2]. In this section, some of the main conclusions and implications for future applications are summarized.

The differences in radio performance to UEs at altitude compared to ground-based UEs are primarily due to two effects:

- Cellular base stations' antennas include a "downtilt" that directs their coverage toward the ground.
- UEs operating at altitude avoid much of the physical clutter that reduces the prorogation of radio signals. UEs at altitude are more likely to have an uninterrupted line-

of-sight to the base station antenna and thus experience “free space” propagation conditions.

Neither of these effects is straightforward. Generally, the downtilt effect favors UEs at ground level, but the complete 3D coverage pattern of the base station antenna can still have spurious lobes that are directed toward the sky and therefore certain areas above the antenna may still receive very good coverage.

In contrast to the case with downtilt, the propagation conditions generally favor UEs at altitude over those at ground level. However, this brings its own problems as increased propagation over longer distances increases the interference to and from neighboring cells.

As with all aspects of radio performance, the coverage for UAVs is subject to statistical variation and can vary widely depending on the precise conditions. Trials and simulations have shown that, in general:

- The improved propagation overcomes the effect of the downtilt to give UEs at altitude stronger signals.
- UEs at increasing altitude receive worse signal-to-noise performance on the downlink due to interference from adjacent cells. However, the probability of performance degrading to a point where coverage outage becomes a possibility is similar to that for ground users.
- On the uplink, UEs above ground transmit at lower power but still cause more interference to adjacent cells than ground-based UEs.
- At higher altitudes, cell coverage can become fragmented due to the spurious upper lobes of base station antennas.
- Handovers operate effectively but may take several seconds to perform and, due to the different coverage characteristics at altitude, may be made to distant cells.

Modifications to power control algorithms and handover algorithms for UAVs can help improve performance and mitigate the undesirable effects of the different radio conditions.

These imply:

- UEs operating at altitude can coexist with ground-based UEs in existing networks, provided they are not present in overwhelming numbers.

- Optimization of parameters and algorithms to take account of UEs operating at altitude will be beneficial to the industry.
- UAVs should be tolerant of occasional gaps in transmission due to handover performance or temporary degradation of the signal to noise ratio.

Obviously, the differences in radio propagation at altitude and at ground level are determined by the physical properties of the environment, but other factors mentioned above (e.g., the base station antenna design and coverage pattern) are under network operator control. Current network design is optimized only for coverage at ground level and in local buildings. As UAVs become a more significant user of network services, then network operators may evolve the design of their networks to improve coverage at altitude. It is expected that modification to base station antennas and changes to other parameters can improve coverage at altitude while maintaining network performance at ground level. Work in 3GPP described above provides a deeper understanding of the technical problem domain and solutions that can be adopted by network operators and UAV UE manufacturers to optimize the system performance for UAVs. In the meantime, a number of actors in the market are already offering proprietary service-enhancing features that address UAV requirements.

Traffic QoS Management

LTE, and in the future 5G, will support different QoS Classes. Communications is provided via bearers and each bearer is assigned a QoS Class Identifier (QCI) that defines the QoS of that bearer. There are nine QCI classes defined in LTE which vary depending on whether they have guaranteed minimum and maximum bit rates or not (Guaranteed Bit Rate [GBR] or Non-GBR), their relative priority, maximum packet delay, and maximum packet loss. For QCIs with a guaranteed maximum bit rate, the guarantees for uplink (UAV->Network) and downlink (Network->UAV) may be specified independently.

Table 3 – 3GPP QCI Values

QCI	Bearer Type	Priority	Packet Delay	Packet Loss	Example
1	GBR	2	100 ms	10^{-2}	VoIP call
2	GBR	4	150 ms	10^{-3}	Video call
3	GBR	3	50 ms	10^{-3}	Online Gaming (Real Time)
4	GBR	5	300 ms	10^{-6}	Video streaming
5	Non-GBR	1	100 ms	10^{-6}	IMS Signaling
6	Non-GBR	6	300 ms	10^{-6}	Video, TCP based services e.g. email, chat, ftp etc
7	Non-GBR	7	100 ms	10^{-3}	Voice, Video, Interactive gaming
8	Non-GBR	8	300 ms	10^{-6}	Video, TCP based services e.g. email, chat, ftp etc
9	Non-GBR	9	300 ms	10^{-6}	Video, TCP based services e.g. email, chat, ftp etc

UAV applications are expected to select an appropriate QoS class to fulfill the needed service. For example, command and control for a UAV with a remote operator using real-time control could use QCI class 4 with bit rates sufficient to carry uplink video to the operator. An autonomous commercial drone could for example use a more relaxed QCI, such as 5. Because each bearer can be assigned a different QCI, different types of traffic to and from the UAV may be assigned different QoS handling.

6. Conclusions

Mobile cellular systems are a very widely available and trusted communications infrastructure. Their capabilities for data transfer, location finding, and identification are highly relevant to the needs of UAVs. These are summarized in Table 4.

Table 4 – Summary of Value of Cellular System Capabilities to UAVs

Cellular Capability…	… can Meet Requirements for:
Reliable, wide area, trustworthy communications	Command and control of UAVs (including beyond line of sight). Flight planning and coordination with other airspace users/UAV formations. Telemetry capture, including for regulatory compliance. Data-intensive payloads (e.g., Light Detection and Ranging (LIDAR), high definition video).
Trusted location services with possibility of corroboration of data via multiple location techniques	Navigation. Enforcement and verification of flight plans and "no fly" rules. Trusted, independent, corroboration of location data.
Identification of devices	Device and owner identity tracing.

Studies and the experience of many users have shown that today's LTE networks are already capable of providing high quality services to UAVs. Future 5G networks and enhancements to LTE in progress will make cellular systems even more capable and include specific features targeting UAV needs. Cellular systems will have a valuable role in addressing the evolving operational and regulatory requirements needed to ensure convenient, cost-effective, safe, and secure use of UAVs.

Good collaboration between companies and industry bodies in the cellular sector and the UAV sector is encouraged to align requirements and capabilities between these complementary technologies.

7. Abbreviations

3GPP	Third Generation Partnership Project
A-GNSS	Assisted Global Navigation Satellite System
AP	Access Point
ASIC	Application Specific Integrated Circuit
BDS	BeiDou Navigation Satellite System
E-CID	Enhanced Cell ID
E-SMLC	Enhanced-Serving Mobile Location Centre
FAA	Federal Aviation Authority
GBR	Guaranteed Bit Rate
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
LIDAR	Light Detection and Ranging
LPP	LTE Positioning Protocol
MBS	Metropolitan Beacon System
MEMS	Microelectromechanical systems
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NLOS	Non-Line of Sight
NR	New Radio
OTDOA	Observed Time Difference of Arrival
PPP	Precise Point Positioning

ProSE	Proximity Services
QCI	QoS Class Identifier
QoS	Quality of Service
RTK	Real Time Kinematics
sUAS	Small Unmanned Aircraft system
SV	Space Vehicle
TBS	Terrestrial Beacon System
UAS	Unmanned Aircraft system
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UTDOA	Uplink Time Difference of Arrival
UTM	UAS (qv) Traffic Management
USS	UAS (qv) Service Supplier
VoIP	Voice Over Internet Protocol
WLAN	Wireless Local Area Network

8. References

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