Joint Authorities for Rulemaking of Unmanned Systems

WHITE PAPER: USE OF MOBILE NETWORKS TO SUPPORT UAS OPERATIONS

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1. INTRODUCTION

1.1 Purpose of the document

Regulators and authorities face a challenge in keeping pace with rapid developments in technology. This is, without any doubt, the case for Unmanned Aircraft Systems (UAS).

To respond to such challenge, regulators are increasingly focusing on performance-based regulation (i.e. technology agnostic rules and technical standards for minimum safety developed by industry) and risk-based regulation (i.e. certification by independent and accredited entities, without direct involvement of the Aviation Authority).

In the context of UAS communications, JARUS WG5 proposed some time ago to initiate an activity to have a better understanding of the technical capabilities of mobile phone communication networks to support the Command Control and Communications[1]

As a result of that proposal, WG5 has prepared this document to provide JARUS members and the wider UAS community with an understanding of:

- the main possibilities that services based on Mobile Communications Networks (MCN) can provide to overcome intrinsic constraints and contribute to unleashing the full potential of UAS operations; and
- the main regulatory and standardisation aspects that need to be considered for the use of such services based on MCN for safer and more secure UAS operations.

The paper also explains certain relevant aspects of mobile communications in the context of UAS operations for the benefit of those in the JARUS community who may not be familiar with mobile network technology.

Nowadays, most of the operations carried out by small UAS rely on direct Radio Line Of Sight (RLOS) systems. This technology has been well proven over the years with model aircraft, although such operations predominantly are done in undemanding environments, such as in open areas within Visual Line of Sight (VLOS) of the pilot.

New UAS operational scenarios (e.g. Delivery, Urban Mobility, etc.) have been opened by the emergence and proliferation of UAS using a direct RLOS C2 Link, which gives an idea of the power of this technology but, at the same time, it is clear that direct RLOS cannot solve all these emerging challenges, having, thus, to rely on new supporting technologies. Mobile Communications Networks (MCNs) are one such technology.

In the scope of this document MCNs are always Beyond Radio Line of Sight (BRLOS) systems. They are implemented by an extensive terrestrial network infrastructure. The RLOS component can be seen at the “last hop” between their terrestrial base stations and the Unmanned Aircraft (UA).

MCNs may also help to solve some of the challenges in civil UAS operations such as remote identification, alternative and dynamic UAS geolocation, and Beyond Visual Line of Sight (BVLOS) operations.

[1] The C2 Link is the technical means to implement ATC/pilot exchanges telecommand and telemetry to manage the flight of the UA safely.

1.2 Scope

This document is mainly focused on small and medium civil UAS (i.e. flown in the in the 'open' and 'specific' operation categories)[2] whose size, weight and power (SWaP) restrictions limit the application of communications technologies typically used in the mainstream aeronautical industry.

The certified operation category is out of the scope of this paper because the characteristics of those systems are more similar to manned aircraft. However, it does not mean that MCN networks are not suitable for this category.

The use of MCN to deliver a C2 Link and other services to a UAS in all categories is being initiated by organisations like RTCA, and EUROCAE. There is also a collaboration between the GSMA and GUTMA (the Aerial Connectivity Joint Activity - ACJA) that is focusing on the provision of the C2 Link using MCN.

The aim of this paper is to show the worldwide UAS community the ways in which MCN can support UAS operations and the challenges, regardless of the varying regulations among countries.

National Aviation Authorities (NAAs) may use this document to better understand the broad vision of the UAS ecosystem and how mobile networks can improve UAS safety and security, as well as the productivity of the UAS market.

This document may also help Communications Service Providers (CSPs) understand the capabilities that mobile network services need to offer in order to support the UAS ecosystem.

Connectivity via MCNs may be helpful to enable complex operations in the future, although not all UAS will necessarily require connectivity. The need for MCN connectivity will depend on the various operational requirements (for example operational scenarios and operational risk, considering also the level of automation implemented in the UAS)**.**

This document is not intended to be prescriptive, but rather simply set forth the benefits and considerations of using MCN to support UAS operations

For each operation, an assessment of communication critical issues shall be performed in order to determine command-and-control technologies that better fits with the operational requirements.[3]

1.3 Definitions

a) **C2 Link**: The data link, however implemented, between the UA and the controlling function that manages the flight of the UA, (including ATM functions when relayed by the RPA and supported by the C2 Link). This is based on the ICAO definition that applies to Remotely Piloted Aircraft Systems. (**ICAO)**

b) **Visual Line-Of-Sight (VLOS):** A type of UA operation in which the remote pilot maintains continuous unobstructed and unaided visual contact with the UA, allowing the remote pilot to monitor the flight path of the UA in relation to other aircraft, persons, and obstacles, for the purpose of maintaining separation from them and avoiding collisions. (**JARUS)**

c) **Beyond Visual Line Of Sight (BVLOS):** A type of UA operation in which the remote crew, including the remote pilot and possible observers, is unable to maintain continuous unobstructed and unaided visual contact with the UA. **(JARUS)**

d) **Mobile Cellular Network (MCN):** For the purposes of this document, Mobile Communication Networks are telecommunications networks that implement the specifications developed by the 3rd Generation Project Partnership (3GPP). Devices, termed User Equipment (UEs), connected to MCNs, for example consumer terminals such as smartphones or tablets, are able to maintain

[2] For more information see Section 4."*UAS ECOSYSTEM REVIEW"*

[3] This document does not necessarily mean to exclude any other technologies from discussion and consideration as alternative solutions.

continuous communication in physical motion and within and between MCN service provisions. **(JARUS)**

e) **Vehicle to Vehicle Communications (V2V):** Vehicle-to-vehicle (V2V) communications ability to wirelessly exchange information about the speed and position and direction with nearby vehicles shows great promise in helping to avoid crashes, ease traffic congestion, and improve the environment. **(NHTSA)**

f) **Remote pilot station (RPS**): The component of the remote pilot aircraft system containing the equipment used to pilot the remotely piloted aircraft. Also called Control Unit (CU) **(ICAO)**

g) **Communication Service Providers (CSP):** A communications service provider is an organization that provides telecommunications services supporting some combination of information and media services, content, application services over networks, leveraging the network infrastructure as a rich, functional platform. **(Gartner)**

h) **Very Low Level (VLL).** An operation below the height of 500 ft above ground level (AGL) or other current local minimum flight height limits. **(JARUS)**

i) **Connected UAS:** An UA and its associated elements related to safe operation, which may include control stations, data links, support equipment, payloads, and is connected with cellular networks. **(JARUS)**

j) **Unconnected UAS:** An UA and its associated elements related to safe operation, which may include control stations, data links, support equipment, payloads, and is not connected with cellular networks. **(FAA Order 8130.34D)**

k) **Geo-fencing (geofencing)**; An automatic function to limit the access of the UA to airspace areas or volumes provided as geographical limitations based on the UA position and navigation data according to the EASA Prototype Commission Regulation on UAS. **(EASA Prototype Commission Regulation on UAS JAR doc 14 – OPS Cat A & B – WG 2)**

l) **Geographical Limitation:** A restricted or prohibited airspace volume, where UA operations are not allowed. Also called No fly Zones. **(JARUS)**

m) **User Equipment:** Device allowing a user access to network services. **(3GPP)**

n) **Designated Operational Coverage (DOC):** Volume within which a communication service is available in compliance with designation by competent authorities if applicable, with sufficient performance including availability, continuity, integrity and timeliness and, if applicable, with sufficient radio signal quality and protection from other users of the electromagnetic spectrum. **(ISO CD 23629-12)**

o) **UAS Traffic Management (UTM):** Set of traffic management and air navigation services aiming at safe, secure and efficient integration of multiple manned and unmanned aircraft flying inside the respective DOC of each service. **(ISO CD 23629-12)**

p) **UTM Service Provider:** An organization playing the role of a UTM actor which provides, normally in exchange of a fee, digital data and information to UTM users, which may choose to take advantage from the offered service. **(ISO CD 23620-12)**

1.4 Acronyms

AMC:	Acceptable Means of Compliance
ARC:	Air Risk Class
ATC:	Air Traffic Control
ATCO:	Air Traffic Control Officer
ATM:	Air Traffic Management
BRLOS:	Beyond Radio Line Of Sight
BVLOS:	Beyond Visual Line of Sight
C2 Link	Command and Control
C3 Link:	Command and Control and Communications
CDMA:	Code Division Multiple Access
CE:	Conformité Européene
CSP:	Communication Service Provider
DOC	**Designated Operational Coverage**
EASA:	European Union Aviation Safety Agency
EGPRS:	Enhanced General Packet Radio Service
EMBB:	Enhanced Mobile Broadband
EU:	European Union
FAA:	Federal Aviation Administration
GNSS:	Global Navigation Satellite System
GPRS:	General Packet Radio Service
GPS:	Global Positioning System
GSM:	Global System for Mobile Communications
ICAO:	International Civil Aviation Organization
ISM	**Industrial, Scientific and Medical**
ISO:	International Standards Organization
ISP:	Internet Service Provider
ITU:	International Telecommunications Union
JARUS:	Joint Authorities for Rulemaking on Unmanned Systems
Kbps:	Kilobytes per Second
LTE:	Long Term Evolution (3GPP 4G technology)
MCN:	Mobile Communication Network
MMS:	Multimedia Messaging Service
mMTC:	massive Machine-Type-Comms
MNO:	Mobile Network Operator
NAA:	National Aviation Authority
QoS	Quality Of Service
RLOS:	Radio Line of Sight
RP:	**Remote pilot**
RPASP:	Remotely Piloted Aircraft Systems Panel
RPS	Remote Pilot Station
RTCA:	Radio Technical Commission for Aeronautics
SARPS:	Standards and Recommended Practices
SMS:	Short Message Service
SORA:	Specific Operation Risk Assessment
SP:	Service Provider
SWaP:	Size Weight and Power
UA:	Unmanned Aircraft
UAS:	Unmanned Aerial System
UCU:	UAS Control Unit
UE:	User Equipment
UMTS:	Universal Mobile Telecommunications System
URLLC:	Ultra-Reliable Low-Latency Communication
UTM:	UAS Traffic Management

V2V: Vehicle to Vehicle

VHF: Very High Frequency

VLL: Very Low Level

VLOS: Visual Line of Sight

WAP: Wireless Access Protocol

WG: Working Group

2. MOBILE CELLULAR NETWORKS

2.1 What are MCN?

A mobile cellular network (MCN) or mobile network is a communication network where the last link is wireless. This network is composed of a **web of base stations**, each of them covering a delimited area around it called **"cell"** (hence, the alternative term of "cellular networks" is often used for mobile networks). User terminals (Phones Laptops, UAS), normally called user equipment (UEs) are connected by this last radio link.

For a voice call, MCNs connect users through the network infrastructure of a Mobile Network Operator (MNO) responsible for managing the services. A user's mobile telephone[4] communicates with a base station, which in turn links to the core network of the operator. This routes the communication to the corresponding party on the fixed network or via other base stations, possibly in other MCNs.

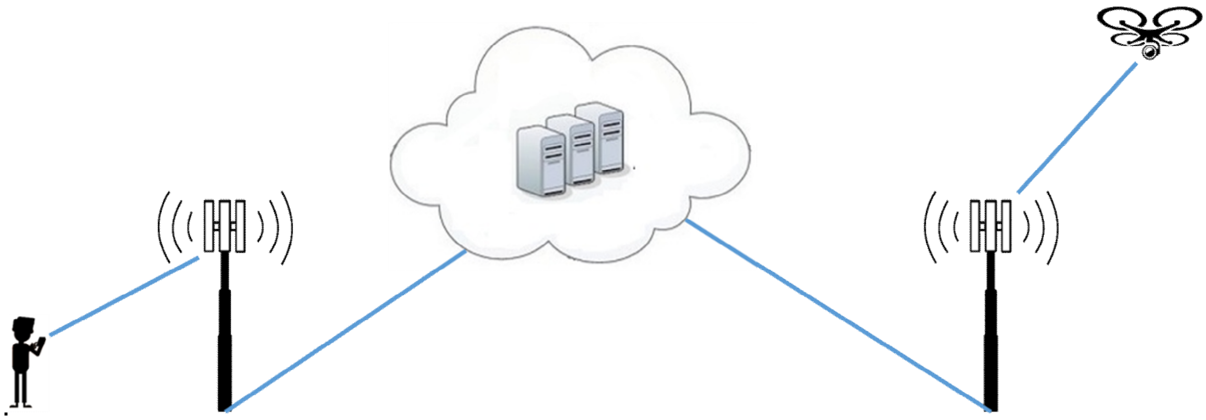


Figure 1: One use-case for use of a MCN service – VLOS and BVLOS operation.

For communications purposes, a cellular user must be within the range of one or more base stations. To cover the maximum territory possible, as well as to ensure that users are always able to communicate, MNOs deploy thousands of base stations so that users experience the service with seamless continuity across cells.[5]

[4] Or other user's mobile device with capability to communicate through the network

[5] http://radio-waves.orange.com/en/radio-networks-and-antennas/how-does-a-mobile-network-work

2.2 Historical Review of MCN

Mobile technology was created in the 1940s, but it was in the 2000s when it started to have real impact in society. The table below shows the evolution of this technology along the years.

History and development of mobile technology			
Technology	**Description**	**Relevance for UAS**	**Data Rates**
Generation 0 (0G)	In the 1940s mobile radio telephone was the precursor to the first generation of mobile technology. The most commonly known service of this generation is Push-to-Talk (PTT), where the receiving and the transmitting channel were separate and the end user needed to press a button to switch mode (half duplex communication).	Not relevant for UAS	
First generation of cellular phone technology (1G)	The first commercial launch of the First Generation cellular network took place in Japan by NTT in 1979. It provided a full-duplex communication, which means that the two parties involved in a call can speak and listen at the same time. There was no universal standard, but a multitude of local standards (NMT, TACS, and AMPS). Cell phones broadcasted analog (not digital) signals. This technology could not access the Internet or transmit text messages.	Not relevant for UAS	Not implemented in many systems. Typical 2.4 Kbps; max 22 Kbps if available.
2G	In the 1990s the GSM standard got introduced. The communication has become digital (analog signals got digitised into 0s and 1s), circuit-switched and voice communications were encrypted for the first time. There are 2 standards: • **Code Division Multiple Access (CDMA).** This standard operates in the same 800MHz band used by the previous analog transmissions. • **Global System for Mobile Communications (GSM).** This standard operates in the 900-1,900MHz band and is more prevalent globally 2G networks and phones could transmit non-voice data. This ushered in the era of text messaging, in the form of Short Message Service (SMS) and, later, Multimedia Message Service (MMS). It also enabled access to the Internet, for email, web browsing. In 2015 2G counted about 60% of the total connection worldwide[6].	Not relevant for UAS	9.6 - 14.4 Kbps (circuit data)
2.5G	The term 2.5G was used to indicate the generation that introduced the packet-switched domain in addition to the circuit-switched domain. The most important technologies were General Packet Radio Service (GPRS) and Wireless Application Protocol (WAP). For the first time cellular network provided support for IP with GPRS. In optimal conditions GPRS could reach a bit rate of about 150 Kbps. Next, Enhanced Data rates for GSM Evolution (EDGE) was introduced, which is commonly referred as 2.75G. EDGE was standardised by 3GPP as part of the GSM family and increased in capacity compared to GPRS and reached about 384 kbps. The introduction of GPRS and the enhancement to EGPRS helped to move forward to the new coming generation.	Low relevance for UAS	15 - 384 Kbps
3G	3G networks feature increased bandwidth and transfer rates that better accommodate the transfer of digital data necessary for Internet access and the use of web-based applications.	This level is becoming relevant for cellular	50 – 144 Kbps (1xRTT);

[6] https://gsmaintelligence.com/metrics/53/796/data/?report=52fd2ef22db04).

	3G is approximately 13 times faster than 2G. 3G standards: • **CDMA2000** is an evolution of the previous CDMA standard. • **Universal Mobile Telecommunications System** (**UMTS**) is an evolution of the GSM standard. 3G is the de-facto minimum requirement for using a smartphone today.	connectivity of UAS.	200 – 384 Kbps (UMTS); 500 Kbps – 2.4 Mbps (EVDO)
4G	4G could provide data transmission rates up to 1Gbps, which is more than 30 times the rate of 3G networks. The result is very high bandwidth, low latency and exceptional quality of service (streaming video on the phone becomes possible). 4G standard: • **Long Term Evolution (LTE).** This standard delivers data download rates to mobile users up to 300Mbps. 3G's maximum 2Mbps data download speed is close to that offered by many home Internet service providers (ISPs); DSL, for example, typically delivers speeds in the same 2Mbps range. With speeds approaching to 1Gbps, cellular Internet is suddenly faster than what you get at home—or sitting in your local Wi-Fi hotspot.	Currently UAS would use this mobile connectivity the most.	LTE: >100 Mbps with adequate spectrum (15 or 20 MHz)
5G	5G should deliver significantly increased operational performance (e.g. increased spectral efficiency, higher data rates, low latency), as well as superior user experience (near to fixed network but offering full mobility and coverage). It also features the concept of slicing (virtual splitting of physical networks) supporting guaranteed resources (QoS) for critical communication and edge computing (Multi-access edge computing, MEC) capabilities allowing to build more power demanding applications' architectures with the support of edge computers located in base stations or other edge servers located close to UEs (separated only by radio link). 5G needs to cater for massive deployment of Internet of Things, while still offering acceptable levels of energy consumption, equipment cost and network deployment and operation cost. It needs to support a wide variety of applications and services.	In the near future, 5G will enhance UAS capabilities	Several types of mobile data service are available: eMBB, NBIoT, LTE-M, (described in more detail below).

Table 1– Summary of mobile technology generations[7]

[7] Source: http://www.informit.com/articles/article.aspx?p=2021961

2.3 Benefits of MCN for UAS

MCN could help the UAS sector develop its full potential, because UAS operations are expected to be global, interoperable and scalable. Also this type of technology is evolving and 5G is the next step in the evolution process. MCN could enable UTM Services like flight management, update dynamic no fly zones or enable remote identification while ensuring data protection, privacy and security. MCN would also allow to serve plenty of UAS at the same time in the same area.

This technology can also facilitate to overcome some operational constraints faced by the UAS industry and assist in the creation of innovative services, in particular widespread BVLOS operations and increased UAS connectivity.

2.4 Introduction to 5G capabilities

5G is the latest generation of mobile technology, engineered to greatly increase the speed and responsiveness MCN. It will also enable a sharp increase in the amount of data transmitted over wireless networks due to more available bandwidth, use of higher frequency bands (i.e. millimetre wave spectrum) and a new radio air interface.

5G will additionally offer improvements in speed, capacity and latency, guaranteed by using network slicing, which allows mobile operators to create multiple virtual networks within a single physical 5G network. This capability will enable wireless network connections to support specific uses or business cases and could be sold on an “as-a-service” basis. For example, MNOs could provide 5G slices specifically designed to better support C2 Link requirements after specific assessments.

Multiple UAS, for example, may benefit from a network slice that offers extremely fast, low-latency connections so aircraft could navigate in real time, sharing multi-source information from the surrounding environment with each other. In case of UAS developing autonomous operations that does not need any network to supply command and control link, a network could still enable cooperation between the autonomous UAS and other UAS or manned aircraft.

5G networks and services will be progressively deployed over the next several years, to accommodate the increasing capabilities and benefits delivered by communications with mobile and internet-enabled devices. Overall, 5G is expected to generate a variety of new applications, uses and business cases that will include the new cases of UAS operations.

	3G	4G	5G
Deployment	2004-05	2006-10	2020
Bandwidth	2mbps	200mbps	>1gbps
Latency	100-500 milliseconds	20-30 milliseconds	<10 milliseconds
Average Speed	144 kbps	25 mbps	200-400 mbps

Figure 2: 5G Performances and capabilities.

2.4.1 How 5G works

This technology is a new service architecture, a new collection of service definitions and also a selection of different radio technologies. In practice, because mobile networks must be backwards compatible with earlier versions, 5G architecture will operate the 5G New Radio (5G NR) alongside Long Term Evolution (LTE), which is a 4G technology (there are several configurations possible). To achieve much greater local capacity near ground level, 5G NR wireless signals may be transmitted via large numbers of small cell stations located in places like light poles or building roofs using beamforming technology. This could benefit UAS flying at very low levels.

Beamforming is a technology that projects the signal in a specific direction, while traditionally the signal is sent in all directions or a fixed direction by changing phases of multiple antenna elements.

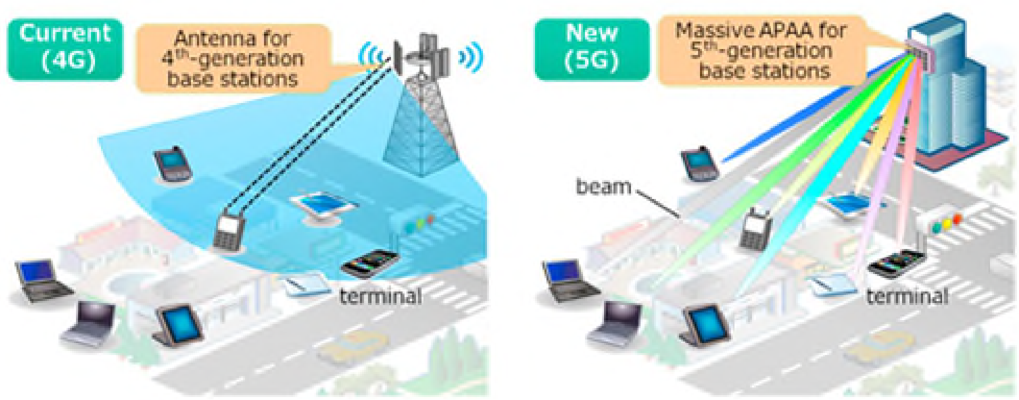


Figure 3: How 4G antennas broadcast signals compared to how 5G antennas beam signals across a city.IEEE Communications Society (Source Mitsubishi)[8].

5G technology may be configurable regarding the needs of the final user and will use different wavelengths depending on the environment to reach the quality and performance objectives.

Using this technology the data rate can be from 10 to 100 times faster than a typical 4G connection.

This technology might become crucial for certain UAS operations. The ability to shape and direct the beam will better support UAS operations.

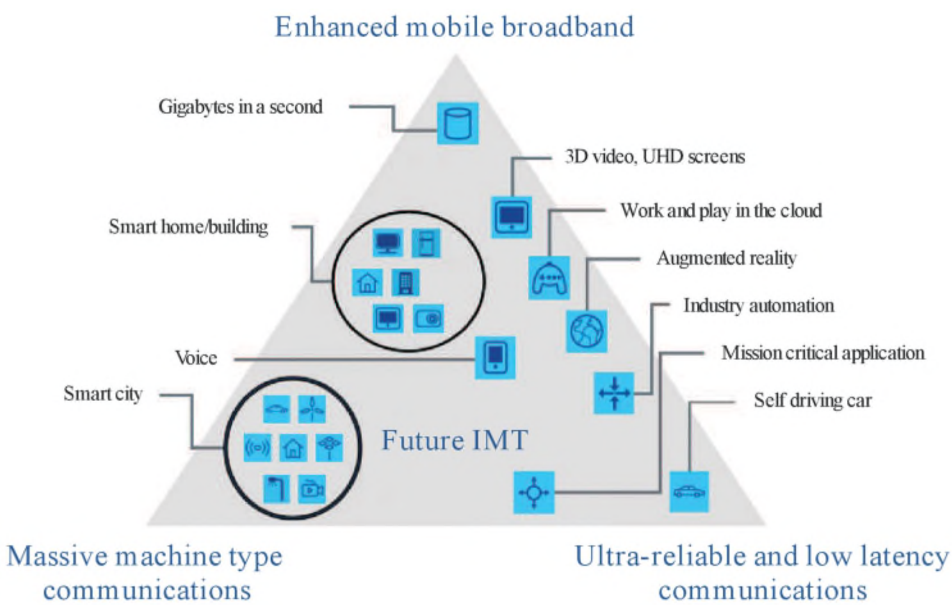


Figure 4: Usage scenarios for IMT 2020.

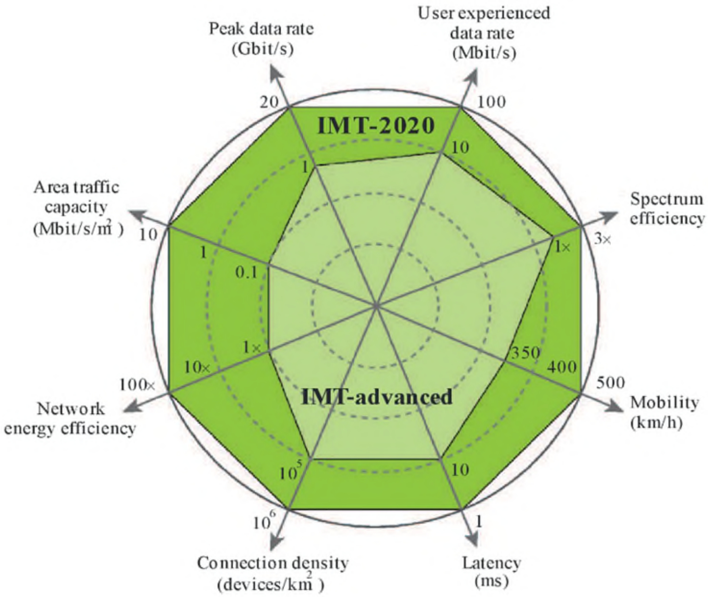
[8] "Mitsubishi Electric's New Multibeam Multiplexing 5G Technology Achieves 20Gbps Throughput," 21 January 2016. [Online]. Available: http://www.mitsubishielectric.com/news/2016/0121.html.

5G improves 4G capabilities significantly, and it has three principal innovations that enable very diverse usage scenarios.

The innovations and usage scenarios shown in Figure 4 are the following:

- ***eMBB, Enhanced Mobile Broadband :*** In this scenario the user data speed requirements across a wide coverage area are very high.
- ***uRLLC, Ultra-Reliable and Low-Latency Communications:*** In this scenario there are strict latency and reliability requirements for critical type communications, such as remote surgery operations, autonomous vehicles or tactile Internet.
- ***mMTC, Massive Machine Type Communications:*** This scenario must support a large number of devices in small areas, which can send data sporadically as is the case of IoT devices.

The following Figure illustrates a comparison of the requirements of 5G versus 4G (known as IMT-2020 and IMT-Advanced respectively in the ITU) [9]



Requirement description	IMT-Advanced (4G)	IMT-2020 (5G)
Peak data rate: Maximum achievable data rate under ideal conditions per user/device (in Gbit/s)	Downlink peak: 1 Gbit/s	Downlink Peak: 20 Gbit/s Uplink peak: 10 Gbit/s
User experienced data rate: Achievable data rate that is available ubiquitously across the coverage area to amobile user/device (in Mbit/s or Gbit/s)	Downlink peak: 10 Mbit/s	Downlink Peak: 100 Mbit/s Uplink peak: 50 Mbit/s
Latency: The User Plane latency is the contribution by the radio network to the time from when the source sends a packet to when the destination receives it (in ms)	10 ms	4 ms for eMBB 1 ms for uRLLC
Mobility: Maximum speed at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/-RAT) can be achieved (in km/h)	Pedestrian: 0 to 10 Km/h Vehicular: 10 to 120 Km/h High Speed Vehicular: 120 to 350 Km/h	Pedestrian: 0 to 10 Km/h Vehicular: 10 to 120 Km/h High Speed Vehicular: 120 to 500 Km/h
Connection density: Total number of connected and/or accessible devices per unit area (per km^2)	100000 devices per Km^2	1 million devices per km^2
Spectrum efficiency: Average data throughput per unit of spectrum resource and per cell (bit/s/Hz)	Downlink peak 15 bit/s/Hz Uplink peak: 6,75 bit/s/Hz	Downlink peak: 30 bit/s/Hz Uplink peak: 15 bit/s/Hz
Area traffic capacity: Total traffic throughput served per geographic area (in Mbit/s/m^2)	0.1 Mbit/s/m^2	10 Mbit/s/m^2
Energy efficiency: Network energy efficiency is the capability of a RIT/SRIT to minimize the radio access network energy consumption in relation to the traffic capacity provided	1x	100x

Figure 5: Comparative of IMT-advanced (4g) vs imt-2020 (5g) requirements (Source ITU R).

As shown above, 5G improves all the parameters of 4G demonstrating the power of this new technology.

[9] https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-BB.5G_01-2018-PDF-E.pdf

3. UAS OPERATIONS: CURRENT COMMUNICATION CONSTRAINTS

UAS regulations that give exemptions to lighter devices have contributed to reinforce the predominance of the small UAS segment, which can be expected to continue growing in the next years.

However, the characteristics of this UAS segment lead to a number of challenging constraints. The following points describe these constraints in relation to communications and signal transmission.

- **Size, weight and power (SWaP), and cost**. Among other aspects, constrain UAS in terms of range and endurance and significantly reduce the technology that can be installed on the UA.
- **GNSS drawbacks**. The availability of very low SWaP and cost-efficient GNSS sensors make it popular and affordable, but this technology has some drawbacks, including the fact that its signals are easily weakened by terrain, vegetation and buildings or even spoofed by hackers.
- **RLOS coverage constrains.** Direct RLOS limits flights beyond VLOS not only in terms of area coverage (shorter range) but also in terms of not being able to operate the UAS (or making it difficult) with obstacles between the UAS and the remote control station. This constraint reduces the possibility of performing different operations (Delivery, Surveillance, Traffic Control, Emergencies, etc.) In addition, safety is also affected using RLOS in complex environments because lost C2 Link events increase the risk of a UAS out of control that can lead to fatal harm.
- **Proliferation of UAS.** The expected proliferation of UAS operations (Figure 6) has become of great concern regarding safety, security and privacy, especially in densely populated areas or areas with critical infrastructures. These concerns need to be satisfactorily addressed to enable those UAS operations. Addressing these concerns motivates the development of UTM concepts.

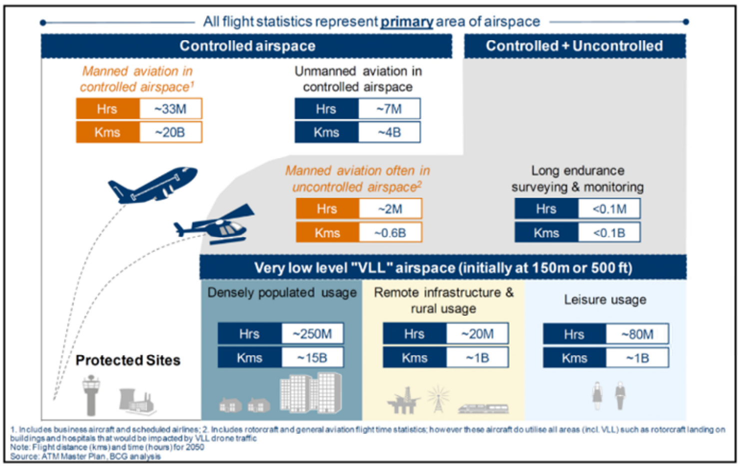


Figure 6: Forecast of the future UAS usage.

4. UAS ECOSYSTEM REVIEW

Small UAS are typically those under 25 kg[10] operating below 400 ft. (121 m) AGL. This values (or a close one) has been adopted as mass threshold[11] in a significant number of national and supranational (e.g. EU) regulations for low intrinsic risk operations that can be considered under category of operations A ('Open') or lower end of B ('Specific')[12]

UAS ecosystem is vast and heterogeneous, including from low weight toys to huge aircraft with trans-ocean capabilities of several thousands of kg. Thus, communication requirements are not similar in each scenario.

An assessment in which communications should be evaluated is necessary, and the final choice will depend on the adjustment of the technology with the intended operations. MCN would be an option among another communication technologies like SATCOM, WiFi, or other radio communications.

4.1 Unconnected UAS scenario

UAS operations, including from recreational flights to high-level professional ones carried out until the date of releasing this document, mainly rely on RLOS systems.

The most common RLOS systems currently used are:

- AM/FM.
- Wi-Fi (in 2.4 GHz and 5 GHz) in command and control and also in video streaming.
- Bluetooth technology (in 2.4 GHz)

The majority of the UAS described in this point flies outside controlled airspace and does not require Air Traffic Management (ATM) services.

In case of UAS flights in controlled airspace, ATC has only information of the beginning and the end of the UAS operations through pre-strategic coordination with the UAS operator. Any update or warning related to the UAS operation suitable to be transmitted to the ATC will be communicated by fixed or mobile phone.[13]

In the Unconnected UAS scenario, there is limited coordination between UAS flights because the position of each UAS is only known to its own pilot. Conflict resolution relies on the 'see and avoid' procedures and any coordination between operations is merely voluntary.

Remote pilot or UAS operator identifications mainly rely on the installation of a physical license plate on the frame of the UA, impossible to be read without physical interception of the UA and sightings of flights

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[10] Typically with a characteristic dimension (e.g. wingspan, main rotor diameter, distance between rotors …) of less than 3 m.

[11] See section 8.1.2 for a brief description of these categories. Taking it from those regulations for model aircraft (existing only in some countries), which was the best known (and, in most cases, only) reference with regard to small unmanned aircraft.

[12] Extracted from "Remotely piloted aircraft system (RPAS)concept of operations (CONOPS) for international IFR operations

[13] Note: other RPAS operations by national services or by states coordinate strategically between ATCO Air Navigation Service Providers (ANSPs) and the RPAS operator.

that do not fit within the legal framework are difficult to be penalised by the law enforcement authorities due to the complexity to find the remote pilots in charge.

In summary, interconnectivity is not significant in this scenario and the integration level of mobile networks is very low, being mobile communications in this UAS environment mainly restricted to voice communications with ATC and communications between crew members.

Figure 7: Unconnected UAS Scenario.

4.2 Connected UAS scenario

MCN may offer services that make UAS operations more cost-effective, safer and interoperable. This technology may provide continuous coverage with seamless mobility management inside and between Mobile Network Operators (MNOs) coverage areas and could be used by UTM service providers to provide tracking, de-confliction and remote identification, among others.

The increasing interconnectivity will boost the coordination capabilities between unmanned-unmanned and unmanned-manned aviation, increasing the number of flights without compromising safety.

Different communication technologies could be useful in different scenarios and is essential evaluate operational environments to select the one that better fits with it.

It is foreseeable that flights in low risk level (i.e. very low level agricultural spraying in rural areas) would require less connectivity than higher risk levels flights (i.e. urban delivery). Nevertheless, some connectivity requirements could be required by the National Aviation Authority (i.e. remote identification or automatic no fly zone updating) to allow operations in some areas or geographical zones.

In addition, some security improvements could be achieved with the use of MCN like the geo verification of the aircraft using Radio Position System (RPS) to counteract the possibility of GPS signal spoofing.

Figure 8: Connected UAS scenario.

5. Mobile networks in UTM[14]

The UTM concept is defined as a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. These services rely on a high level of digitalisation and automation of functions, whether they are on board the drone itself, or are part of the ground-based equipment. UTM provides an enabling framework to support routine drone operations, as well as a clear and effective interface to manned aviation, ATM/ANS service providers and authorities.

UTM requires certain technical capabilities that are not currently available with “Unconnected UAS”. To reach a complete and effective integration into UTM airspace, these UAS might need systems that allow them to take advantage of the capabilities that the UTM service provider can offer, such as transmission system of telemetry to UTM services, geo-caging and geo-awareness, electronic identification, etc.

Those individuals that in the future do not have the possibility to fully integrate in the UTM environment may have limited ability to fly in certain zones.

Therefore, the use of telephony networks are highly related to the future of the UTM, as it requires the ability to receive and transmit information globally for the complete integration of Connected UAS within this airspace.

[14] https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20Blueprint%20brochure%20final.PDF

6. MCN BENEFITS FOR THE UAS ENVIRONMENT

Mobile connectivity in UAS can boost the operational capacity of the UAS and reduce costs. This section explains the main benefits of the use of MCN in UAS.

6.1 Keep UAS Size Weight and Power (SWaP)

Conversion from an Unconnected UAS into a Connected UAS means including some extra equipment among which is:

- Cellular modem (mobile module).
- SIM card or equivalent, and a subscription to a MCN service.
- Extra equipment (power sources, cabling equipment antennas, wires, etc.).

Equipment used for trials in initiatives like those used in the most of the test carried out in the last years are not representative of the future Connected UAS.

Generally, that equipment is not optimised in SWaP terms for this purpose. Some trials are carried out adding to the frame of the UA a mobile phone just to connect it to the mobile network. This solution can work for larger UA, but it is not a valid option in the case of lighter UA in which the addition of extra weight would cause a significant performance reduction.

In the near future MCN equipment should be well-integrated into the UAS and keep SWaP impacts low enough to not penalise significantly small UAS characteristics and performance.

Full UAS connectivity keeping it small, light weighted and power efficient needs that the industry develops some changes on constructive patterns and designs, integrating the necessary components in the mainboard of the UAS to enable mobile connectivity.

An innovative way to keep the SWaP requirements while the UAS capabilities keep developing is using the potential of the MCN to move the processing from the UAV to the edge of the MCN network (e.g. base station) with the technology called Multi-Access Edge Computing explained in the point 6.11.

6.2 Improve extended operations

Mobile networks enable UAS BVLOS operations by ensuring connectivity with the drone regardless of the distance between the UA and the operator.

If during the flight, the quality of the link with one base station signal degrades, the system will choose another base station with a stronger connection. This is commonly known as cellular handover, which is a complex process based on several radio parameters that uses the neighbouring of the antennas and could allow flights even in urban areas with a high obstacle density as long as the UA keep within a base station coverage.

6.3 Keep an affordable cost for the UAS operator

One of the main successes of the UAS market today is the relative low cost of small UAS that made it affordable for most of the public. Wireless communications for small UAS operating in direct RLOS (2,4 5,8 Ghz) are cheap and can be used anywhere.

Affordable prices of mobile network components and services would not be supposed an obstacle for the UAS users and the increasing benefits using Connected UAS could help this technology settle in the market.

In this regard, companies that are professionally dedicated to operating UAS may convene extensions to the telephone service they have contracted, assuming only a small increase in the service fee.

In the case that private pilots in the recreational field may contract phone service extensions or in case they do not want to assume extra costs, they might continue using direct RLOS technologies, which do not have extra subscription costs, but may see limitations in the areas in which these UAS operations are carried out.

Despite worldwide communication is not completely possible due to standardization, current deployment of physical mobile 4G and 5G networks solve this problem and (base stations, antennas) allows the use of this “Connected UAS” in most of urban and even rural areas, enabling the capacity to use any UAS worldwide. The future deployment of 5G would bring new set of functionalities and capabilities in the UAS environment and will promote the standardization worldwide.

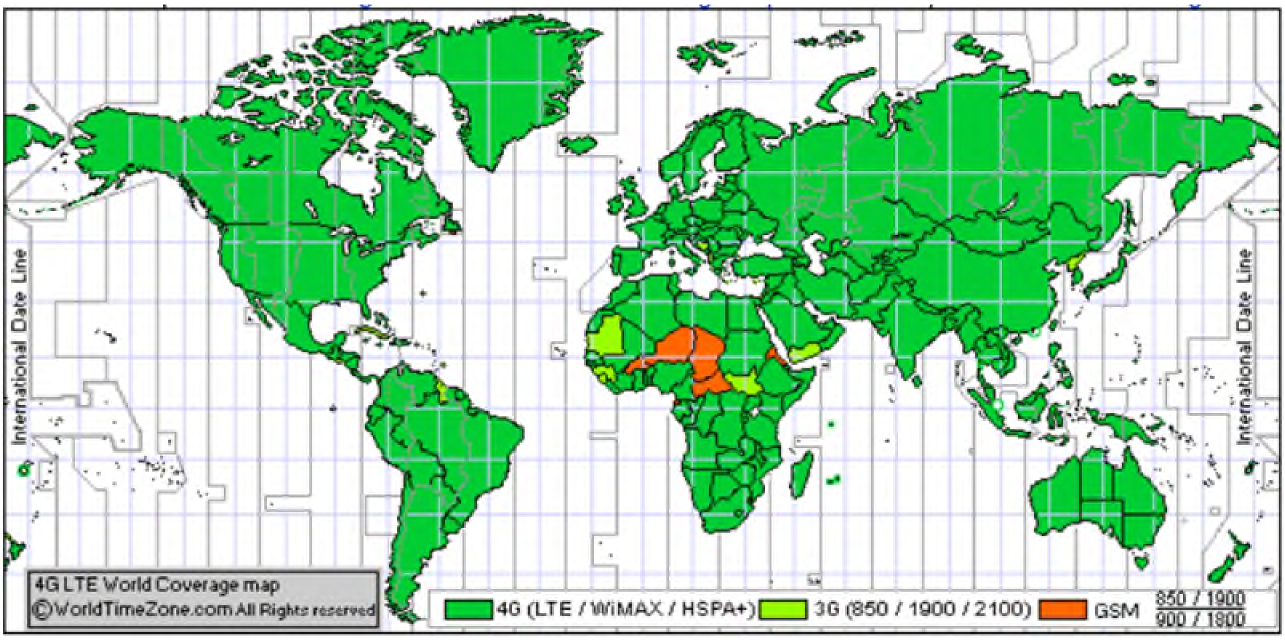

Figure 9 4G: Commercial network world coverage map: (note: the map is purely indicative and might not be accurate). Source: WorldTimeZone.

6.4 Boost interconnectivity

Most of the UAS flying nowadays all over the world have some mild interconnectivity with the internet using MNCs through the smartphone, tablets or laptops that shows telemetry information during the flight working as a remote station.

This mild interconnectivity has been rising up during the last years showing the benefits of sharing relevant information between remote pilots and manufacturers and currently presents the following benefits.

- It could allow safer identifications of UAS operators and remote pilots.
- It could provide some basic UTM services like geo-awareness and geolocation, as long as the UA is directly connected with the mobile phone working as remote control station.

Full integration of UAS will take some additional benefits in some operational scenarios (urban, high density air traffic) that may benefit from an increase in connectivity allowing better performances and higher security rates in complex events, (i.e. broadcast the position even if the C2 Link is not completely available during a loss of control or increase number of UAS operating in the same area at the same time).

6.5 Enhance geo-awareness

Geo-awareness can be used to trigger alerts to the UAS operator or appropriate enforcement authorities, if necessary.

Where a UAS operator needs a temporary permission to fly in a restricted area, the request for authorisation can be forwarded via the mobile network to the relevant authority and the approval can be communicated directly back to the UAS enabling it to fly in a forbidden zone. This capability is directly relevant for the regulatory objectives outlined by the main aviation competent authorities (e.g. EASA, FAA,) in their consultation related to geofencing, geoawarness and no fly zones.

This bi-directional information stream between UAS operators and National Authorities enables the investigation of safety and security issues regarding UAS operations.

In case of a UAS entering a no-fly zone, the trusted authority could request the UAS to leave the no-fly zone. The secure cellular connection can authorise and grant access for trusted parties with the appropriate credentials to communicate with the UAS.

Cellular connectivity can also provide a mean to verify the GNSS position using Radio Position System (RPS) based on MCN to avoid cybersecurity threats like GPS spoofing

6.6 Upgrade flight plan services

Big amounts of information circulates through mobile networks generated mainly by internet users. This extremely large data sets may be computationally analysed to reveal patterns, trends, and associations.

“Connected UAS” could, at the same time, provide raw information to the UTM server and receive processed information like additional services.

All this information can be shown to the remote pilots or even be sent automatically to the UA to update the flight plan in real time to the surrounding conditions, reducing the uncertainty during the flight within the UTM space.

Flight Plan Services could provide the following information:

- Density of people: Information about the density of people in real time. This information can be processed by the UTM service and modify the flight plans of the UA to avoid overflight these areas.

- Meteorological information at very low level: The amount of meteorological information available at VLL layer is limited. The UAS itself can serve as meteorological stations reporting to the UTM service data such as wind speed, temperature, humidity. This data, can be available to the rest of UTM users to optimise their flight plans, avoiding risks.

- Air Traffic Density: As far as the UAS may provide the position information through the mobile network to the UTM servers, an estimation of the air traffic density can be performed. This facility could update the flight plan through the less congested area.

6.7 Provide the right Quality of Service for UA operations

MCNs provide already a variety of Quality of Services (QoS) that can be suited for several services including UAS.

Using the same equipment and infrastructure deployed it would be possible to provide additional bandwidth with expected QoS (guaranteed throughput, latency, etc.). In current scenarios C2 and payload often require completely separate systems/networks, which make the case technically more complex to implement and more susceptible to potential problems. In extreme scenarios, when is not possible to provide satisfactory bandwidth for payload (e.g. HD video transmission), it must be recorded to local storage on-board the UA and can be accessible only after the mission is completed. In MCN such an additional bandwidth can be provided.

This can simplify also the safety of the operation because flight plans would be prepared based on confirmed availability of required network resources and previously agreed level of QoS.

Operators also may reserve if necessary a licensed mobile spectrum that enables widespread, high-quality connectivity for UAS with sufficient capacity to support competitive services and rising usage levels.

Licensed spectrum could give mobile operators access to spectrum that provides broad coverage (i.e. below 1 GHz spectrum bands) and capacity (i.e. above 1 GHz spectrum bands). This system enables safe, reliable, high-speed services over wide areas,

However, the application of licensed spectrum is subject to regulatory constraints specific to each country and should be carefully evaluated by NAAs in conjunction with their spectrum regulatory authorities.

6.8 Increase privacy and security

The mobile communications industry is highly regulated in relation to privacy and data protection due to telecoms-specific regulation, which has led to a good knowledge and practices. This regulation can be implemented by the UAS ecosystem where appropriate.

Cellular connectivity is reliable and encrypted and also supports communication links between UAS operators and public security authorities. These additional safety measures provide enough assurance to support new UAS operations, such as BVLOS flights, including those for disaster response or package delivery.

Mobile networks are complex systems comprising of globally standardised interfaces and functions. The standardisation process allows the mobile networks to be delivered in a unified way; emphasising security and privacy controls. Mobile network infrastructure includes devices, radio bases stations, core network entities and all the technology and links in between. Each technology within the network, requires different security controls. These should be enabled appropriately to provide defence in depth security to the entire network.

6.9 Raise E-Identification

Identification is extremely important in the UAS environment as it expands. Most current flights are done in complete anonymity.

A MCN-based solution could be an effective ways to enable UAS identification / authorisation services, as identity verification and management is already a key component in MCNs

With MCN technology, an UAS can be intercepted by law enforcement using a device similar to a mobile phone or tablet.

Many countries require registration of SIMs in handsets. Mobile operators therefore have experience with fulfilling customer and device registration requirements. This experience is directly relevant to the principles established by EASA in unmanned aircraft regulation related to UAS registration and electronic identification[15].

While in some countries the SIM purchase is possible without user identification, the problem of trusted identification remains open and a viable solution could be the exclusion of prepay SIMs and the exclusive use of subscriptions in UAS operations.

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0947&from=EN

Identification with MCN has been studied by some administrations as a valid method to identify some UAS operations[16]. Another ways to identify the UAS could be the direct broadcast or the physical identification which is commonly used in several countries, but it is the e-identification using mobile networks which allows greater possibilities for UTM.

A UAS with cellular connectivity can communicate, the position of the UA and the position of the remote control station to a central server accessible for the law enforcement that would be aware of any illegality performed by an operator.

6.10 Better communication with ATC

Also known as ATC collaborative interface, will be an integral part of the UTM architecture.

In the initial stage of service implementation, it should be clearly emphasized that no service at any time will take control of the drone (except for situations where, for safety and security reasons, there is a need to use counter drone systems). Therefore, today's two-way communication is based on the transfer of information from the ATC to the drone operator who must take direct action. From the point of view of the telecommunications network, only is needed connection between the operator and the drone.

Interface with ATC will become not only a communication channel with air traffic services, but generally a communication system for transmitting information such as: take-off permission, landing order, information on dynamic reconfiguration of the airspace.

6.11 Multi-Access Edge Computing

The most recent standardization related to MCN brings also the concept of edge computing (Multi-access Edge Computing, MEC). Thanks to this technology it would be possible to host different applications on MNO's infrastructure (MEC servers) located in base stations.

Thus, it would be possible to move computing power of demanding applications (like image/video processing) from the UA to the base station. This solution can reduce the latency and save bandwidth for systems that would require normally to transmit huge amount of data to remote servers for further processing. In this case part or whole processing can be perform close to the source of data (UA), on edge servers and only results of such processing would be sent to remote servers.

The following are other examples of edge applications dedicated to UAS operations:

- Edge servers can host application implementing functionalities of ground control station for instance controlling swarm of drones.
- Applications on edge servers can provide specific services to UAs like broadcasting information about local obstacles.
- Edge applications would provide translation services for altitude measurements alignment of telemetry data.
- Faster and quick analysis of images of the landing area to asses if it is clear and accessible.

This concept may increase the UAS functionalities maintaining the SWaP concept.

[16] MCN is one of the proposed options. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/UAS%20ID%20ARC%20Final%20Report%20with%20Appendices.pdf

7. MCN CHALLENGES

Mobile Communication Networks faces some challenges while developing, but most of them would be especially significant in case of a future in which the density of UAS may increase without improvement of the current MCN infrastructure.

It is foreseeable that the inclusion of Connected UAS in the market may be staggered at first and the low density of UAS using MCN infrastructures would not cause a serious impact on the service neither mobile phone, nor UAS users.

Is foreseeable that the current infrastructure would be updated taking in count new UAS services and researches in the field of MCN supporting UAS operations in a gradual evolution of the service allowing higher densities without significant reduction on safety security and quality standards.

Even so, the following problems must be taken into account

7.1 Interferences

The change in the use of the mobile 4G technology from terrestrial surface to the heights can suppose drawbacks not foreseen by interferences produced between all the terminals to each other on the ground.

This kind of interference produces a moderate impact on UAS usage specially if the MCN is used for the control channel and also is impacting traditional communication services by people using their mobile phones on the ground.

Recent studies from the Aviation Research Centre Switzerland show that: *"As altitude increases, interference also increases as signals are received from an increasing number of base stations. This fact, leads to a reduction in data throughput, especially in the direction of the UAS. Main applications such as e.g. video transmission from the UAS to the ground are less affected.*

In the case of a very high UAS density, the interference in the MCN could increase further. In this case, adjustments on the UAS and in the MCN should be considered to keep the increase in interference under control"[17].

This facts may be solved using mitigation systems, like optimising the antenna shape, directivity and size and also by means of new protocols which improve the selection of the best node in height

In addition, recent tests performed by Qualcom have shown that 4G LTE is viable for operating drones at 120 m and below.

- The signal strength for LTE drones at altitude is very strong despite down tilted antennas
- Handover performance is superior to ground mobile devices
- There is comparable coverage to ground mobile devices.

Whilst these findings are enough for the current uptake of drones and for the initial phase in the market, the need for further optimisation has been identified in the areas of interference mitigation and the optimisation of power control and of the selection of the serving cell. This situation is part of the normal process of continuous evolution of 4G technologies[18].

A 3GPP study was accepted to enhance 4G support for drones, which means the work on improvements is already ongoing.

Regarding the 5G technology, there are issues about the frequency spectrum assigned to 5G applications interfering with aircraft radar altimeters. According to the report, the frequency spectrum from 3.7– to 3.98-GHz, which the Radio Technical Commission for Aeronautics has assigned to

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[17] https://www.zhaw.ch/storage/engineering/institute-zentren/zav/upload/events/swiss_utm_forum_2018/Swiss_UTM_Forum_2018_ARCS.pdf

[15]Reference UAS2Com

[18] (Source: https://www.qualcomm.com/news/onq/2017/05/03/qualcomm-technologies-releases-lte-drone-trial-results)

upcoming flexible 5G telecommunications applications, may “introduce harmful radio frequency (RF) interference to radar altimeters currently operating in the globally-allocated 4.2– to 4.4-GHz aeronautical band.[19]

7.2 Service oversight and supervision.

Since the contribution of MNC for safety and security is not negligible, the organisations of the COM SPs should be under oversight by competent authorities.

ISO CD 23629-12 proposed to distinguish such providers in "safety critical", "safety related", and "operation support".

Depending on this classification, each of these providers would be subjected to different control mechanisms

Applying the principles of the risk based regulation as recommended by SORA, safety critical COM SP could be subject to certification[20] by the aviation authorities, while conformity of safety related and operation support SPs could be verified through industry mechanisms, based on consensus-based standards (e.g. 2nd edition of ISO 21384-3) and evaluation by accredited, independent and competent third parties.

7.3 Quality and availability of the service

Consumers desire quality services, and prefer higher quality of service when price and other cost elements are held constant.

It is foreseeable that 5G services may be concentrated in the surrounding of urban areas. While we are far away from these urban areas the quality and availability of these services will be gradually reduced and replaced by 4G services that have a wider distribution across the territory.

This concept should be taken into account by the UAS operator and an evaluation of the adjustment of the service should be done before starting the UAS operation.

Networks should address the need to provide appropriate Designated Operational Coverage (DOC) and service level for UAS during the flights.

In this aspect, 4D coverage information (3D and time) will become very important to be able to support devices above the ground. In addition, coverage at a given a time, also in the future (prediction) will help to determine the available, communication with the UA and consequently allow the UA operator to take the most appropriate decision, where and when to define contingency actions plans for automatic and autonomous flights.

The 4D coverage information, in real time and in the future, becomes critical factor for risk analysis during the flight preparation as well during the flight execution.

Only if the UAS MCN service reaches the minimum levels across the territory of quality and availability for the consumer, the persistence of that technology is ensured. Thus, service availability and appropriate QoS, and other relevant information (e.g. signal strength), would be crucial from the SORA analysis perspective. It must be assured that during pre-flight analysis and especially during the mission execution, reliable information should be provided by MNOs.

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[19]https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf

[20] According to Volume IV of Annex 6 to the Chicago Convention, the C2 Link CSP, being safety critical, may be certified by an aviation authority or under indirect oversight through the Safety Management of the the UAS Operator.

7.4 Roaming

Roaming enables mobile subscribers to get access to all services that they subscribe to when outside of the geographical area of their mobile operator

This situation would happen usually in transnational operations where the UA changes among different Mobile Network Service Providers.

This issue should be taking into account by the time that a UAS can change the Mobile service provider during the operation and keep flying without resenting the safety of the UAS operation. This transition should be instantaneous to avoid that the UA could be flying without supervision and control.

Roaming service is made possible through Mobile Network Operators who have cooperative agreements to grant each other's customer's access to their network.

This is especially important in trans-national operations because although 4G and 5G technology have common standards worldwide another older technologies could not be compatible with the UA technology depending the technology deployed in each country.

7.5 UAV to UAV communication

The broadcasting of information is a vital concept for situational awareness in manned aviation (transponder concept). Thus this principle must be inherited by unmanned aviation.

UAS operations will highly depend on this kind of communication (ability to broadcast and receive location information).

MCN might support this by means of various broadcasting solution proposals, which could be build upon V2X (vehicle to everything) service:

- Network independent service (based on dedicated, separate from the MCN resources, radio channel)
- Network assisted service (based on dedicated but MCN controlled radio channel)
- Network based service (service "emulating" broadcast type of communication)

First two options require regulatory standardization across all states to designate appropriate frequency channel to be used for this purpose.

Solutions for direct communication between UA in MCN are already available in LTE, but focused and dedicated mostly to automotive market (V2X and especially V2V service). Standardization is still on-going on enhancement in 5G. The same service defined for automotive can be reused for UAS, but there would be small adjustment needed to better support the UAS environment. Such enhancements are already identifying the potential modification needed to better support the need of UAS.

7.6 Antenna deployment for 5G technology.

5G, densification strategies will be amplified, requiring "hyper-dense" network environments that bring even more nodes closer to the end user.

High-frequency millimetre waves, which will help power 5G, are driving hyper-densification, because they are capable of delivering extreme data speeds and capacity to reshape connectivity. The challenge is that millimetre waves have poor transmission—they are susceptible to blockage and typically can't penetrate walls. To solve this, are required converged network solutions—including DAS (cellular distributed antenna systems), small cells and Wi-Fi— that add more base stations, antennas and access points."

In addition, there are some practical limitations to the deployment of 5G MIMO antenna technologies (massive Multiple Input Multiple Output) since they are limited to deployments above 2.5 GHz and advanced antennas in lower bands implies larger size and weight antennas which leads to tower loading issues.

7.7 Lack of practical experience

Currently there is few information about the actual use of MCNs in the field of UAS, but more and more initiatives are being carried out mainly by public and private entities that aim to verify the real conditions of the use of mobile networks in the UAS.

The information obtained through these tests will be of vital importance for the early detection of operational problems that could endanger the application of telephone networks in UAS.

7.8 Other Challenges

The following uncertainties may be analysed in order to develop this technology with the needed levels of safety and security.

- Operating frequency/frequencies;
- Average number of base towers detected at operational altitude;
- Average latency at operational altitude;
- Latency threshold that triggers a lost link procedure;
- Other key performance indicators such as Uplink Received Signal Strength Indicator (RSSI), Uplink Reference Signals Received Power (RSRP), Uplink Reference Signal Received Quality (RSRQ), Heat Map, Uplink Packet Loss, Accessibility (Data/Voice), Retainability (Data/Voice), and Throughput.

8. REGULATION AND STANDARDISATION

As flying machines, UAS are legally considered aircraft and, consequently, they have to comply with the regulatory and standardisation framework for aviation. However, the potential use by UAS of communication services provided by non-aviation operators and infrastructures requires also compliance with regulations and standards for telecommunications. This particular combination of regulatory and standardisation frameworks from different fields presents one of the main challenges faced by regulators and stakeholders to enable the use of MCNs for UAS operations.

Safety has always been a paramount aspect in aviation, which is reputed as one of the safest industries overall. To achieve this, a very robust and rigorous regulatory and standardisation framework needs to be developed alongside with a strong safety culture. Not only the aviation community but society demands that the safety levels achieved in aviation are not degraded by new airspace users like UAS operators.

8.1 European regulation

The radio spectrum decision allows the Commission to adopt implementing decision to harmonise technical conditions with regard to the availability and efficient use of spectrum for the proper functioning of the single market. The Commission may issue mandates to the European Conference of Postal and Telecommunications Administrations (CEPT) for the preparation of such technical implementing measures.

To assist the Commission, two complementary bodies were set up following the Radio Spectrum Decision in 2002, to facilitate consultation and to develop and support an EU Radio Spectrum Policy:

- The Radio Spectrum Policy Group (RSPG) is a group of high-level national governmental experts to help the Commission developing general Radio Spectrum Policy at Community level.
- The Radio Spectrum Committee (RSC) is a committee under Regulation 182/2011/EU which assists the Commission in developing technical implementation measures to ensure harmonised conditions across Europe for the availability and efficient use of radio spectrum.

In addition, the Commission has set up a Spectrum Interservice Group that provides coordination between the various Commission departments, which have responsibility for the wide range of other EU policies which may be affected by allocation policy for radio spectrum (e.g. in transport, research, aerospace, environment, audiovisual policy).

8.1.1 CE Marking[21]

Some supranational entities provide standards to set common rules to the manufacturer to ensure that the final product complies with the local regulation. CE marking tool will be used within European Union and will help to standardise all the UAS industry in the Open and Specific Categories.

In accordance with the Regulation (EU) 2018/1139 of the European Parliament and of the Council, market product legislation (CE marking) ensures compliance with the technical requirements for UAS operated in the ‘open’ category commission delegated regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems also defines the new EU market harmonisation legislation that UAS operated in the ‘open’ category will have to comply with. Compliance is shown by affixing the CE marking and the UAS class to the UAS when it meets the essential technical requirements defined in this proposed regulation telecommunications standards among them.

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R0945

The UAS harmonisation legislation has been drafted in accordance with the reference requirements of Decision No 768/2008/EC16[22] and calls upon the market surveillance activities defined in Regulation (EC) No 765/200817[23.]

The protection of the radio spectrum is set as an essential requirement of Directive 2014/53/EU (RED Directive) on the harmonisation of the laws of the Member States on the marketing of radio equipment, which establishes that radio equipment must be so constructed that it makes and promotes efficient use of the radio spectrum in order to avoid harmful interference.

Verification of compliance with this essential requirement of the Directive is done through harmonised standards that are drawn up and published by ETSI (European Telecommunications Standards Institute) under the mandate of the European Community and which set out the technical details to be complied with by the different existing technologies.

The importance of standardising this type of parameter in radio interfaces is to prevent interference between different technologies and, as previously mentioned, on public health grounds.

8.1.2 Categories of UAS and use of MCN

The basis of the "UAS Operational Categorisation" proposed by JARUS, which has already been implemented in 2017 in Qatar and Georgia and thereafter in the European Union.[24]. According to this risk-based operational categorisation, a UAS operation may fall in one of the following operational categories:

- **Category A ('open'):** category of UAS operations that present a low unmitigated risk. No or low involvement of the competent authority is expected in this category (e.g. no operation authorisation. Risk mitigation is applied through the adoption of operational limitations (e.g. VLOS, VLL, and low UAS mass).

- **Category B ('specific'):** category of UAS operations that exceed the limitations of Category A but present an unmitigated risk that does not require mitigations as robust as in Category C (see below) to reach an acceptable level of risk. Usually, UAS operations require an operational authorisation by the competent authority[25], based on an operational risk assessment performed by the UAS operator[26] from which the necessary risk mitigation measures are derived. JARUS has elaborated the SORA methodology to assist UAS operators in conducting their risk assessment under this category of UAS operations.

- **Category C ('certified'):** category of UAS operations that present a high unmitigated risk, to the extent that in order to mitigate it to an acceptable level, similar (when not the same) requirements as in manned aviation have to be established, including UAS airworthiness certification, UAS operator authorisation and crew licensing.

[22] Decision No 768/2008/EC of the European Parliament and of the Council of 9 July 2008 on a common framework for the marketing of products, and repealing Council Decision 93/465/EEC (OJ L 218, 13.8.2008, p. 82) (http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1493654386469&uri=CELEX:02008D0768-20080709).

[23] Regulation (EC) No 765/2008 of the European Parliament and of the Council of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products and repealing Regulation (EEC) No 339/93 (OJ L 218, 13.8.2008, p. 30) (http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1493654158057&uri=CELEX:02008R0765-20080813).

[24] See EU Basic Regulation for Aviation [ref. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018R1139] and Implementing Act for Open and Specific categories of UAS operations [ref. https://eur-lex.europa.eu/eli/reg_impl/2019/947/oj]

[25] Some States may allow operations under declaration by the UAS operator of compliance with a set of provisions (usually for relatively low unmitigated risk operations)

[26] Some operations may require the involvement of other authorities or organisations, e.g. aerodrome authorities, air traffic services providers (ATSP)

At least in a first stage, the envisioned primary use of MCN by UAS is for small ones mostly operating at very low level (VLL). Most of these UAS operations are expected to fall in the categories A ('open') and B ('specific'), especially in the latter as more applications in this operational category are expected to benefit from the full potential that MCN can provide.

MCN use for C2 Link services shows a possible relation between categories of potential spectrum for UAS (as proposed by ITU) and categories of UAS operations. As it is depicted, UAS operations in Open and Specific categories might use licensed and non-aeronautical bands, like those for MCN ("cellular networks"), for the C2 Link.

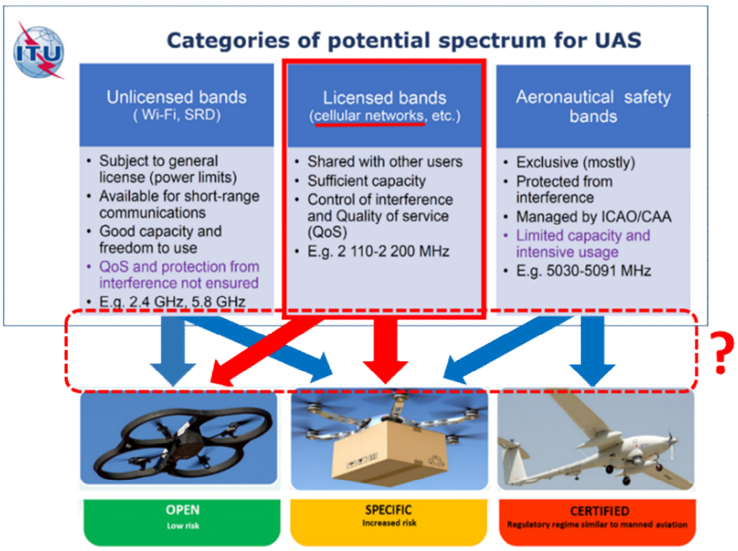

Figure 10: Possible relation between categories of potential spectrum for UAS and categories of UAS operations (source: based on ITU and EASA).

To further illustrate this potential use of MCN, RTCA indicated in its 'UAS access to airspace' report (2017) [27]the following type of use cases with UAS weighing less than 55 lb (~25 kg) as examples of potential use of LTE networks:

- Operations over people (public events);
- Rural, contained area operations;
- Rural, linear operations;
- Suburban/urban (dynamic operations);
- Small cargo (networked operations).

Most UAS operations in above use cases would fall in category B ('Specific')

To evaluate the defences within the operation and to determine the associated level of robustness and warranty needed by the operator Operational Safety Objectives (OSOs) have been created in the framework of the Specific Operations Risk assessment (SORA) developed by JARUS[28].

EASA trend is not to prescribe specific technology for each UAS operation and keep a technology agnostic point of view letting the market and operators choose the solutions that better fits with the intended operation complying some criteria about guaranty and integrity.

[27] UAS Advisory Committee – Special Committee Task Group 2: Access to Airspace Focus Group 1: sUAS BVLOS in the Mode C Veil (DAC SC TG2 FG1)

[28] http://jarus-rpas.org/content/jar-doc-06-sora-package

Below are the tables that explain each of the OSOs related to MCNs.

OSO #6

TECHNICAL ISSUE WITH THE UAS		LEVEL of INTEGRITY – Low	LEVEL of INTEGRITY – Medium	LEVEL of INTEGRITY – High
OSO #06 C3 link characteristics (e.g. performance, spectrum use) are appropriate for the operation	Criteria	• The applicant determines that performance, RF spectrum usage[1] and environmental conditions for C3 links are adequate to safely conduct the intended operation. • The UAS remote pilot has the means to continuously monitor the C3 performance and ensures the performance continues to meet the operational requirements[2].	Same as Low[3].	Same as Low. In addition, the use of licensed[4] frequency bands for C2 Link is required.
	Comments	*[1] For a low level of integrity, unlicensed frequency bands might be acceptable under certain conditions, e.g.:* • *the applicant demonstrates compliance with other RF spectrum usage requirements (e.g. for EU: Directive 2014/53/EU, for US: CFR Title 47 Part 15 Federal Communication Commission (FCC) rules), by showing the UAS equipment is compliant with these requirements (e.g. FCC marking), and* • *the use of mechanisms to protect against interference (e.g. FHSS, frequency deconfliction by procedure).* *[2] The remote pilot has continual and timely access to the relevant C3 information that could affect the safety of flight. For operations requesting only a low level of integrity for this OSO, this could be achieved by monitoring the C2 link signal strength and receiving an alert from the UAS HMI if the signal becomes too low.*	*[3] Depending on the operation, the use of licensed frequency bands might be necessary. In some cases, the use of non-aeronautical bands (e.g. licensed bands for cellular network) may be acceptable.*	*[4] This ensures a minimum level of performance and is not limited to aeronautical licensed frequency bands (e.g. licensed bands for cellular network). Nevertheless some operations may require the use of bands allocated to the aeronautical mobile service for the use of C2 Link (e.g. 5030 – 5091 MHz).* *In any case, the use of licensed frequency bands needs authorization.*

TECHNICAL ISSUE WITH THE UAS		LEVEL of ASSURANCE – Low	LEVEL of ASSURANCE – Medium	LEVEL of ASSURANCE – High
OSO #06 C3 link characteristics (e.g. performance, spectrum use) are appropriate for the operation	Criteria	Consider the assurance criteria defined in section 9 (low level of assurance)	Demonstration of the C3 link performance is in accordance with standards considered adequate by the competent authority and/or in accordance with means of compliance acceptable to that authority.	Same as Medium. In addition, evidence is validated by a competent third party.
	Comments	*N/A*	*National Aviation Authorities (NAAs) may define the standards and/or the means of compliance they consider adequate. The SORA Annex E will be updated at a later point in time with a list of adequate standards based on the feedback provided by the NAAs.*	*N/A*

OSO#13

DETERIORATION OF EXTERNAL SYSTEMS SUPPORTING UAS OPERATION BEYOND THE CONTROL OF THE UAS		LEVEL of INTEGRITY – Low	LEVEL of INTEGRITY – Medium	LEVEL of INTEGRITY – High
OSO #13 External services supporting UAS operations are adequate to the operation	Criteria	The applicant ensures that the level of performance for any externally provided service necessary for the safety of the flight is adequate for the intended operation. If the externally provided service requires communication between the operator and service provider, the applicant ensures there is effective communication to support the service provisions. Roles and responsibilities between the applicant and the external service provider are defined.		
	Comments	*N/A*	*N/A*	*Requirements for contracting services with Service Provider may be derived from ICAO Standards and Recommended Practices - SARPS (currently under development).*

DETERIORATION OF EXTERNAL SYSTEMS SUPPORTING UAS OPERATION BEYOND THE CONTROL OF THE UAS		LEVEL of ASSURANCE		
		Low	Medium	High
OSO #13 External services supporting UAS operations are adequate to the operation	Criteria	The applicant declares that the requested level of performance for any externally provided service necessary for the safety of the flight is achieved (without evidence being necessarily available).	The applicant has supporting evidence that the required level of performance for any externally provided service required for safety of the flight can be achieved for the full duration of the mission. This may take the form of a Service-Level Agreement (SLA) or any official commitment that prevails between a service provider and the applicant on relevant aspects of the service (including quality, availability, responsibilities). The applicant has a means to monitor externally provided services which affect flight critical systems and take appropriate actions if real-time performance could lead to the loss of control of the operation.	Same as Medium. In addition: • The evidence of the externally provided service performance is achieved through demonstrations. • A competent third party validates the claimed level of integrity.
	Comments	*N/A*	*N/A*	*N/A*

8.1.3 EUROCAE

The Council of EUROCAE is responsible for approving the establishment of new Working Groups (WG) and for the definition of their work programmes, taking account of submissions made by any aviation stakeholder and in particular EUROCAE members. The Council reviews and approves all documents prior to their publication.

The Technical Advisory Committee (TAC) develops the EUROCAE Technical Work Programme (TWP). The purpose of this document is to provide an overview of the ongoing technical standardisation activities currently undertaken by EUROCAE together with a strategic outlook on the anticipated technical standardisation activities to be potentially undertaken by EUROCAE, in order to illustrate the extent of the current and future EUROCAE work.

Some subgroups are currently working in communications

- WG-105 SG-21/ UAS C2 Datalink
- WG-105 SG-22/ Spectrum
- WG-105 SG-23/ Security

8.2 North America Regulation

8.2.1 ASTM International

ASTM International, formerly known as American Society for Testing and Materials, is an international standards organisation that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. The organisation’s headquarters is in West Conshohocken, Pennsylvania.

Founded in 1898 as the American Section of the International Association for Testing Materials, ASTM International predates other standards organisations such as the BSI (1901), IEC (1906), DIN (1917), ANSI (1918), AFNOR (1926), and ISO (1947).

It has released a specification that provides a consensus standard for an application to a nation's governing aviation authority (GAA) for a permit to operate a small unmanned aircraft system for commercial or public use purposes. It is intended for all small UAS that are allowed to operate over a defined area and in airspace authorised by a nation's GAA. Unless otherwise specified by a nation's GAA, this specification applies only to UA that have a maximum gross take-off weight of 25 kg (55 lb) or less. This specification covers general command and control (C2) requirements, C2 system spectrum requirements, C2 Link requirements, UA requirements, and fly-away functionality.[29]

8.2.2 RTCA

RTCA, Inc. is a private, not-for-profit corporation based in Washington DC that develops consensus-based standards regarding communications, navigation, surveillance, and Air Traffic Management (ATM) system operations and technical performance. It functions as a Federal Advisory Committee to present recommendations to the Federal Aviation Administration (FAA) for policy, program, and regulatory consideration. These same recommendations are used by the private sector for system development, investment, and related business decisions.[30]

Due to increasing use of Unmanned Aircraft Systems (UAS) by public organisations, and recognition that UAS operations will continue to grow, SC-203 was established in October 2004. It is chartered to develop recommended UAS Minimum Aviation System Performance Standards (MASPS) necessary to mitigate the technical and operational challenges of integrating UAS into the National Airspace System (NAS). SC-203 Terms of Reference (TOR) include delivery of:

- UAS system-level MASPS,
- UAS control and communications MASPS, and
- UAS sense and avoid MASPS.

SC 203 was responsible for developing consensus-based recommendations and standards regarding UAS communications, navigation, surveillance, and air traffic management system issues that are provided to FAA. ASTM International Committee F38

RTCA provides the FAA with recommendations on technical standards for all types of avionics. RTCA is working on developing standards for Detect and Avoid (DAA) equipment and C2 Link radio equipment.

C2 Link radios are key to approval of UAS by the FAA. This standard will allow aircraft equipment manufacturers to build radios for controlling UAS that meet FAA safety requirements.

SC-203 was replaced by SC-228 and has two working groups one for C2 Links and one for DAA systems. SC-228 is in the process of adding additional working groups including one to address to uses of cellular technology for UAS operations. The C2 Link working group has published a MOPS (DO-362) and a MASPS (DO-377) and updates for these documents are currently in progress. The DAA working group has published a MOPS for DAA (DO-365), a MOPS for Air-to-Air radars (DO-366), and a MOPS for Ground Based DAA systems (DO-381) and updates for these documents along with a MOPS for EO/IR sensors are currently in the works. The updates to these documents are working to expanding the standards to cover all airspace.

SC-228 has produced two documents released by RTCA: C2 Link Systems MASPS (DO-377 reference), and C2 Data Link MOPS (Terrestrial) (DO-362 reference).

[29] https://www.astm.org/Standards/F3002.htm

[30] http://www.uasresearch.com/documents/yearbook/066-67_Contributing-Stakeholder_RTCA.pdf

8.3 International Organizations

8.3.1 International Standard Organization (ISO)

ISO has established Sub-Committee SC/16 (UAS) in the context of its Technical Committee TC/20 (Aerospace). Currently ISO is developing several standards applicable to the UAS ecosystem, among which:

- ISO 21384-3 whose 1st edition covers only the UAS operators, but whose 2nd edition is expected to cover also the C2 Link CSPs;
- ISO 23629-12 covering the UTM SPs, including those offering COM services;
- Several standards on UTM covering the architecture and semantics to exchange data among all UTM actors.

Compliance with ISO standards may be verified by ISO certifying bodies (variously known as conformity assessment bodies, notified bodies or qualified entities). The possible voluntary certification of a COM service providers related to UAS operation may constitute an Acceptable Means of Compliance (AMC) with aviation regulations, where those exist and where this is acceptable to the competent authority; facilitate the oversight through the operator safety management system, which would otherwise require tremendous effort from the operator and when SAIL level in SORA would require a high level on assurance robustness for COM external services.

8.3.2 Remotely Piloted Aircraft System Panel (RPASP)

The Remotely Piloted Aircraft Systems Panel (RPASP) coordinates and develops ICAO Standards and Recommended Practices (SARPs), Procedures and Guidance material for remotely piloted aircraft systems (RPAS), to facilitate a safe, secure and efficient integration of remotely piloted aircraft (RPA) into non-segregated airspace and aerodromes.

The RPASP, in collaboration with other ICAO expert groups, undertakes specific studies and subsequently develops provisions to facilitate the safe, secure and efficient integration of RPA into non-segregated airspace and aerodromes while maintaining the existing level of safety for manned aviation.

Some of the aspects that this panel are working on are protection criteria and the safety margin required for C2 Link systems operating in frequency bands that are not dedicated to either Aeronautical Mobile Route Services or Aeronautical Mobiles Satellite Route Services, or the implementation of aeronautical services in frequency bands dedicated to either Aeronautical Mobile Route Services or Aeronautical Mobiles Satellite Route Services and the protection criteria.

8.4 TELECOMMUNICATION STANDARTS

Telecommunications standards (wire and wireless) are the underlying "laws" that govern the emerging Global Information Highway and the existing telephone system. Telecommunications networks in every country in the world utilise formal telecommunications standards to physically interwork. Without public agreements and the telecommunications standards that codify such agreements, wide-area voice and data communications would not be possible.

The integration of the MCN devices installed in UAS does not imply a significant change in the current regulations, since it is about integrating an existing technology (radiotelephone modem) in unmanned aerial systems. For this reason, the applicable regulations regarding the use of frequencies will not imply a significant change in the regulations of the countries involved in the short term.

Before any massive deployment of mobile communications in UAS environment should be proved that massive use of telephony systems sent to the air cannot cause interference or dysfunction to another users and general public. Such studies should be focused in both LTE and 5G.

The main organisations that currently are working in the field of telecommunications standards applied to UAS are the following.

8.4.1 International Telecommunications Union (ITU)

The International Telecommunications Union is a treaty organisation of the United Nations which has as members each country on the planet.

The standards work in the ITU are divided into two sections, ITU-Telecommunications (ITU-T) and ITU-Radiocommunications (ITU-R). Each section is organised into Study Groups.

Study Groups are divided in Working Parties which are further divided as needed to address specific topics. Topics for the Working Parties are primarily generated through World Radiocomunications Conference (WRC) agenda items.

WRC's are typically held every 4 years and the Working Parties perform studies in support of the agenda items. During the period leading up to the 2012 WRC (WRC-12), the ITU Working Parties produced Reports M.2171, M.2205, and M.2237 dealing with the C2 Link and M.2204 dealing with the DAA system. These reports led to the allocation of the 5030-5091 MHz band for UAS C2 Links and determination that the existing aeronautical radar bands were sufficient to support UAS DAA requirements at WRC-12.

Work continued on SATCOM based C2 Links and at WRC-15 an allocation was made for SATCOM frequencies. This SATCOM allocation is scheduled to be reviewed and updated at WRC-23.

Some contributions have been done about the integration of mobile networks to enable C2 link on UAS. In which is show the potential of 5G as a C2 Link option in UAS Environment.[31]

8.4.2 European Telecommunications Standards Institute (ETSI)

The European Telecommunications Standards Institute (ETSI) is an independent, not-for-profit, standardisation organisation in the telecommunications industry (equipment makers and network operators) in Europe, headquartered in Sophia-Antipolis, France, with worldwide projection. ETSI produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies

ETSI publishes 2,000-2,500 standards every year. Since its establishment in 1988, ETSI has published over 30,000 standards. These standards enable key global technologies such as GSM cell phone system, 3G, 4G, DECT, TETRA professional mobile radio system, and Short Range Device including LPD radio, smart cards and many others.

Significant ETSI technical committees and Industry Specification Groups (ISGs) include SmartM2M (for machine-to-machine communications), Intelligent Transport Systems, Network Functions Virtualization, Cyber Security, Electronic Signatures and Infrastructures etc. ETSI inspired the creation of, and is a partner in, 3GPP and oneM2M. All technical committees, working and industry specification groups are accessible via the ETSI Portal

8.4.3 Telecommunications industry (TIA)

Telecommunications Industry Association (TIA) is the formal organisation responsible for the standards of the telecommunications equipment that connects to the US telecommunications network. The TIA is closely aligned with the Electronic Industries Association, an organisation tracing its origin back to 1944.

The Telecommunications Industry Association (TIA) TR-14 Engineering Committee on Structural Standards for Communication and Small Wind Turbine Support Structures seeks participation in its Drones Ad Hoc Group as the group begins efforts to build an industry-specific knowledgebase around the use of unmanned aircraft systems (UAS) technology.

[31] https://www.icao.int/Meetings/UAS2017/Documents/Nikolai%20Vassiliev_Background_Day%201.pdf

8.4.4 3rd Generation Partnership Project (3GGP)

The 3rd Generation Partnership Project (3GPP) unites seven telecommunications standard development organisations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as “Organizational Partners” and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies.

The project covers cellular telecommunications technologies, including radio access, 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.

To address the needs of a new and quickly maturing sector, there has been a lot of activity in the 3GPP Working Groups to ensure that the 5G system will meet the connectivity needs of Unmanned Aerial Systems (UAS) consisting of Unmanned Aerial Vehicles and UAV controllers under the watchful eye of UAS traffic management.

This are the last 3GGP Releases:

- Release 15 - Enhanced LTE Support for Aerial Vehicles
- Release 16 - Remote Identification of Unmanned Aerial Systems
- Release 17 - Study on application layer support for Unmanned Aerial System (UAS)
- Release 17 - 5G Enhancement for UAVs (TS22.125; TS22.261)

9. CONCLUSIONS AND RECOMMENDATIONS

MCN technology is one of the main technological solutions that can facilitate overcoming some operational constraints faced by the UAS industry and assist in the creation of innovative services, in particular widespread BVLOS operations and increased UAS connectivity.

As exposed in previous chapters, key features of mobile networks that can boost the UAS sector are:

- Mobile networks are global, interoperable, and, scalable. They provide a platform for innovative services to develop and benefit the existing ecosystem.
- Existing established mobile communications technology, 4G LTE, is already suitable for a variety of UAS operations, including command and control end mild connectivity.
- The next generation of mobile technology, 5G, provides even greater potential to support UAS with increased speed, reduced latency, and greater bandwidth. They have the potential to be ubiquitous and reliable if implemented everywhere and with sufficient capacity.
- Mobile networks are well-suited to support UTM systems, which will help enable coordination of flight paths promoting the densification of the UAS in the airspace
- Reliable UAS identification and registration are possible by using information stored on an on-board SIM.
- The C2 Link over mobile networks allows for UAS operations over longer distances with a very high degree of autonomy, replacing proprietary short range control links.
- Mobile operators already draw on their extensive experience in addressing data protection, privacy and security issues. Similar techniques could ensure that UAS operations meet the highest security standards.

From a regulatory point of view, the technologically agnostic vision may tend to allow MCNs to compete on equal terms with other existing technologies and the use of a technology over others would depend of the benefits provided by each solution.

MNO should adapt their services to offer communication levels of coverage and continuity of the network with greater guarantees than those required with voice communications, due to the greater risk posed by coverage failures in UAS environment.

Rulemaking should be open enough to allow the introduction in the market of new technologies whenever this solution offers similar levels of safety and security letting MCN settle down gradually in the market as a suitable option in the Open and Specific Categories.

New services provided by both private companies and public authorities related to UAS should be designed thinking in the interconnected environment just to synchronise the operability of the whole system among all the stakeholders and ensure the success of the transition to the future UAS scenarios.

Finally, 5G has the potential to change the way our world connects and the speeds at which we engage online, but the technology must be introduced in a safe manner, which implies the need of testing prior to re-allocating any spectrum band so that any new use of spectrum does not significantly impact safety.

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