"5G for Drone-based Vertical Applications"

D1.4 Report on UAV business and regulatory ecosystem and the role of 5G

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Executive Summary

A core barrier for commercial drone services is the need for line of sight (LOS) between the UAV (Unmanned Aerial Vehicle) and its pilot -that is normally under 500 m in urban areas- due to the existing remote control restricted transmission capabilities. Such a limit does not allow many sophisticated drone services to be performed at present. Most of the commercial drone services require automated beyond visual line of sight (BVLOS) flights. To enable BVLOS use cases, more scalable, reliable and secure connectivity is required, which can be provided by mobile networks. Additionally, versatility of 5G mobile networks supports the development of new services and it is noteworthy that the big telecommunication providers over the world have already launched trials in 2019-2020 to investigate 5G networks in UAV use cases. In accordance, the basic premise of the 5G!Drones project is that the 5G technology will offer the technical means and thus reveal new opportunities for the realisation of enhanced UAV services.

The purpose of this document, namely Deliverable D1.4 that reflects the work of 5G!Drones' Task 1.1 Analysis of the UAV business and regulatory ecosystem and the role of 5G technology, is to deliver a detailed analysis of the current state of the UAV market, its regulation and legislation, and investigate how 5G technology (which is also still evolving) is expected to contribute to the drone's business.

The analysis identifies key application areas where 5G technology can help to provide new or advanced services, and how each stakeholder in the UAV service-related value chain (UAV equipment vendors, vendors of telecommunications equipment, network operators, UAV service providers, regulatory bodies), and the entire society in general, can benefit from these developments. At the same time, the document pays particular attention to regulatory aspects, since the related legislation performs UAV flight operations and to use cellular (LTE or 5G) technology on-board a drone is currently subject to significant changes and may have impact on both how UAV vertical services should operate and how the 5G!Drones trials will be executed. The activities of this task and the reported outcome provide feedback . for the execution of the pre-trials and trials.

It is noteworthy from the study that globally and by 2030 four main sectors, Infrastructure and Construction; Agriculture; Logistics; Air Taxis that are expected to dominate about 70% of the drone services. Total value of drone services market will be 150billion USD in 2030. In the public sector UAV use cases, the report analyses further the following areas of use: Police, Rescue and drones in governmental areas to prevent pandemics. Since February 2020, drones have been actively used in Spain, France, China, USA to fight against the spread of COVID-19, a coronavirus pandemic. It has broadened societies' awareness of the potential of drones and contributed to innovation of drone services.

Thereafter the regulatory framework governing the three 5G!Drones trial locations (France, Finland, Greece) is examined in detail, revealing all related aspects such as scenarios and rules for drone flights and the permission to add the 4G/5G device on board to drone. It is worth mentioning that from 01.07.2020, national rules will be gradually replaced by a common EU regulation (Commission Delegated Regulation (EU) 2019/945, Commission Implementing Regulation (EU) 2019/947) and Commission Implementing Regulation (EU) 2020/639. The purpose of this reform is to create a truly harmonised drone market in Europe with the highest level of safety. In practice, it means that once a drone pilot has received an authorisation from its state of registry, he/she will be allowed to freely circulate in the European Union.

In the next deliverable (D1.7 planned at the end of the project in May 2022) the framework of analysis will be further updated and enriched, taking into consideration all the project developments, achievements and results along with the prevailing market, business, regulatory and 5G advances during the next phases of the project. 5G!Drones trials, their results and rest project achievements will be fully investigated to form the foundations for a novel UAV operations framework within a niche business, market and regulatory environment, where 5G UAV cases will be available, new business

models will be introduced and new regulations will apply and guide UAV business and market related activities.

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List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation Cellular Technology
5GS	5G system
AAS	Active Antenna Systems
AGL	Above Ground Level
AKA	Also-Known-As
A2Vs	Advanced Aerodynamics Vessels
ATC	Air Traffic Control
ATM	Air Traffic Management
BS	Base-station
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CAA	Civil Aviation Authority
CAGR	Compound Annual Growth Rate
CEPT	Conférence Européenne des administrations des Postes et des Télécommunications (European Conference of Postal and Telecommunication Administrations)
COVID-19	Coronavirus disease 2019
DBSs	Drone base stations
DGAC	Direction Générale de l'Aviation Civile (French Civil Aviation Authority)
dFPL	drone Flight Plan
DL	Downlink
DTT	Digital Terrestrial Television
Dx.y	Deliverable number y of the Work Package x
EASA	European Aviation Safety Agency
EC	The European Commission
ECC	Electronic Communication Committee (in CEPT)
eMBB	Enhanced Mobile BroadBand
eNodeB	E-UTRAN Node B, also known as Evolved Node B
ETSI	European Telecommunications Standards Institute
EVLOS	Extended Visual Line of Sight
eVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Agency (in the USA)
FSS	Fixed Satellite Service (earth to space)
GCS	Ground Control Station
GDPR	General Data Protection Regulation
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPT-C	GPRS Tunnelling Protocol communication protocol
HCAA	Hellenic Civil Aviation Authority
HD	High-definition (video)
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunications
IoT	Internet of Things
ISS	International Space Station
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
KPIs	Key Performance Indicators

LAANC	Low Altitude Authorization and Notification Capability in the US
LIDAR	Light Detection and Ranging
LMF	Location Management Function
LTE	Long-Term Evolution
MAP	French “Manuel d’Activités Particulières” - Specific Activities Manual
MFCN	Mobile Fixed Communications Network
mMTC	massive Machine-Type Communication
NG RAN	Next Generation Radio Access Network
NS	Network slicing
OPEX	Operating expense
RC	Radio Communication
RPAS	Remotely Piloted Aircraft Systems
SAR	Search and Rescue
SESAR JU	The Single European Sky ATM Research Joint Undertaking
SLA	Service-Level Agreement
SORA	Specific Operations Risk Assessment
SPoC	Single point of contact
sUAS	small Unmanned Aerial System
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UE	User-equipment
UL	Uplink
uRLLC	Ultra-Reliable and Low Latency Communication
UTM	Unmanned Traffic Management
VLOS	Visual Line of Sight
WP	Work Package

1 INTRODUCTION

1.1 Objective of the Document

The primary objective of this deliverable is the initial presentation and analysis of the UAV market, business and regulatory ecosystem within the newly formed 5G environment and its trends.

Basic premise of the 5G!Drones project is the optimal exploitation of the 5G technology by the UAV industry since the advent of 5G is expected to provide new technical means and new opportunities for the provision of enriched and niche UAV services and applications. Within this framework, the purpose of this deliverable is to provide an initial analysis of the current state of the UAV market with a particular focus on the role of 5G technology in it and the corresponding regulatory environment that is applied. The undertaken analysis will identify key application areas, where 5G technology can provide new or enhanced services, and how each stakeholder in the UAV-service-related value chain (such as UAV equipment vendors, vendors of telecommunications equipment, network operators, UAV service providers, UAV operators, regulatory bodies), and the society in general, can benefit from these developments. At the same time, this deliverable will pay particular attention to regulatory aspects, since the related legislation to perform UAV flight operations is currently subject to significant changes that may have impact on both how UAV vertical services should operate and how the 5G!Drones trials will be executed [1].

The activities of T1.1 Analysis of the UAV business and regulatory ecosystem and the role of 5G technology and their outcomes will be initially reported in D1.4 through a high level analysis of the current status and trends, and later on they will be further updated, elaborated and analysed in D1.7, taken into consideration all the project advances, achievements and results along with the prevailing market, business and regulatory framework during the next phases of the project. In addition, the initial activities of T1.1 already provided valuable input to the rest WP1 tasks for the appropriate refinement and detailed description of the target use case, scenarios and architecture. Similarly, T1.1 aims also to contribute over the next months to several WP2 and WP4 activities, intending to fully support the successful execution of trials and analysis of their results from a market, business and regulatory perspective. WP2 focuses on the design and implementation of the system that will be used for trial execution, and will expand on the high-level architecture design. WP4 focuses on the Integration and trial validation.

In this regard, the market and mainly the regulatory analysis delivered by D1.4 will be fully exploited for the appropriate design of trials and trials executions.

1.2 Structure of the Document

This Deliverable is structured in five chapters:

- Chapter 1 presents an introduction of the deliverable focusing on its objectives, structure and target audience.
- Chapter 2 presents and analyses the current UAV business areas with focus on UAV markets and services related to commercial, governmental and 5G!Drones related use cases. In parallel market and business-related trends are presented per use case area.
- Chapter 3 presents and analyses the overall regulatory framework, including UAV flights and 5G spectrum policies, and their impact to the prevailing use cases. Special focus is provided to the local regulatory framework of the three countries where the 5G!Drones trials will be performed (France, Finland and Greece) along with the potential upcoming impact and timeline during the 2020-2022 period.
- Chapter 4 presents and analyses the role of 5G in UAV areas while it also highlights the applicability of 5G benefits in the 5G!Drones use cases and scenarios that will be trialled.

- Chapter 5 concludes this deliverable.

1.3 Target Audience

This deliverable is mainly addressed to:

- **The Project Consortium** to validate the project objectives, since D1.4 provides an appropriate business, market, regulatory and 5G related framework in which all partners will perform their project activities. In this regard, the business, market, regulatory and 5G analysis delivered by this report also supports the trial controller architecture, trials design along with the trials executions at a later stage of the project.
- **The Research Community and funding EC Organisation** by presenting the market conditions and regulatory framework and how they are efficiently linked to with 5G technology and the project's activities.
- **The UAV industry and stakeholders** who will become aware of the UAV advances and the current market, business and regulatory framework and how and to what degree it will be affected by the advent of 5G technology.
- **The general public** to obtain a better understanding of the UAV business areas, UAV market and vertical use-cases which will be trialled in the 5G!Drones project and how they will be advanced by 5G technology.

1.4 Scope of the Analysis

The market and regulation analysis presented in this document targets the commercial and governmental UAV services, while military services are considered out of the scope. The study is focused on UAV services and software solutions which will be most affected by 5G technology and not UAVs manufacturing. The focus derives from the project's slogan "5G for Drone-based Vertical Applications".

The regulation section puts special emphasis on countries where trials are planned to be conducted (Finland, France and Greece). It also discusses EU current and future regulation, which is expected to change in 2021.

5G technology is also evolving with each new 3GPP release. The basic services are already defined in the Rel. 15 that serves as the basis for our analysis as already deployed in the project's testbeds. However, Rel. 16 [174] and Rel. 17 [120] as key enablers are also considered and studied to a certain extend.

European, the US and Asia data are used in this report, as both regions have a relatively similar level of drone-related services as well as regulation. However, it should be noted that significantly more reports and articles have been published on the US drone services market.

As a final remark, UAVs can be classified by altitude and weight. This report focuses on the analysis of the low altitude small UAVs that are mainly used in the provision of drone-related services. FAA defines small UAVs the ones satisfying the following conditions:

- Weight <= 25 kg.
- Speed <= 158 km/h.
- Altitude <= 120 m AGL (400 feet) [2].

2 UAV BUSINESS AREAS

The purpose of this chapter is to offer a detailed analysis of the current state of the UAV market with a focus on the role of 5G technology.

In November 2016, SESAR JU[1], that coordinates the research and innovation in Aviation Traffic Management (ATM), published the European Drone Outlook Study. This Study has been widely referred to since then, as by 2020 a similar Europe-wide study has not been repeated. SESAR JU performed an economic impact analysis of the entire value chain for each of the areas of demand and revealed the potential for a European market exceeding EUR 10 billion annual economic impact by 2035 and further growing past EUR 15 billion annually by 2050 as unmanned aviation propels the market forward [3].

The SESAR indicated in 2016 that 'The majority of government and commercial potential demand for drones is expected to perform beyond visual line of sight (BVLOS) missions, highlighting the need for connectivity for the majority of drones' [3]. An interesting picture of the drone demand evolution is depicted in Figure 1.

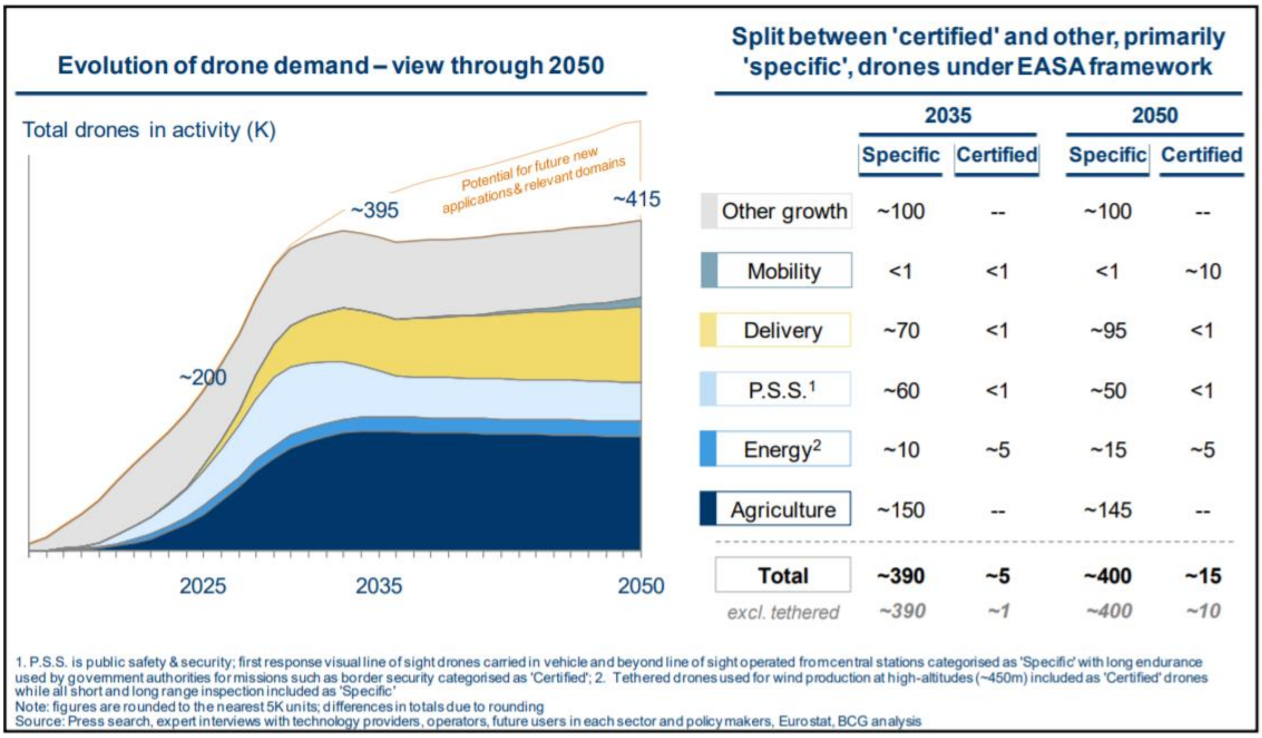


Figure 1 Demand outlook by industry domain [3]

It is interesting to note that SESAR JU has not specifically identified the Construction business, which is classified under 'Other Growth'. SESAR JU predicts that the maturation of UAV services will take place by 2030, when the main industry domains will emerge and the volume of all drone services will

[1] The Single European Sky ATM Research (SESAR) project was set up in 2004 as the technological pillar of the Single European Sky initiative. The SESAR Joint Undertaking (SESAR JU) was established in 2007 as a public-private partnership to harness the research and innovation expertise and resources of the entire ATM community. Founded by the European Union and Eurocontrol, the SESAR JU has 19 members, who together with their partners and affiliate associations represent over 100 companies working in Europe and beyond.

then remain relatively the same. It is worth noting that SESAR (as shown in Figure 2) does not anticipate the wider deployment of drones related to Air mobility (drone taxies, etc.) until 2035.

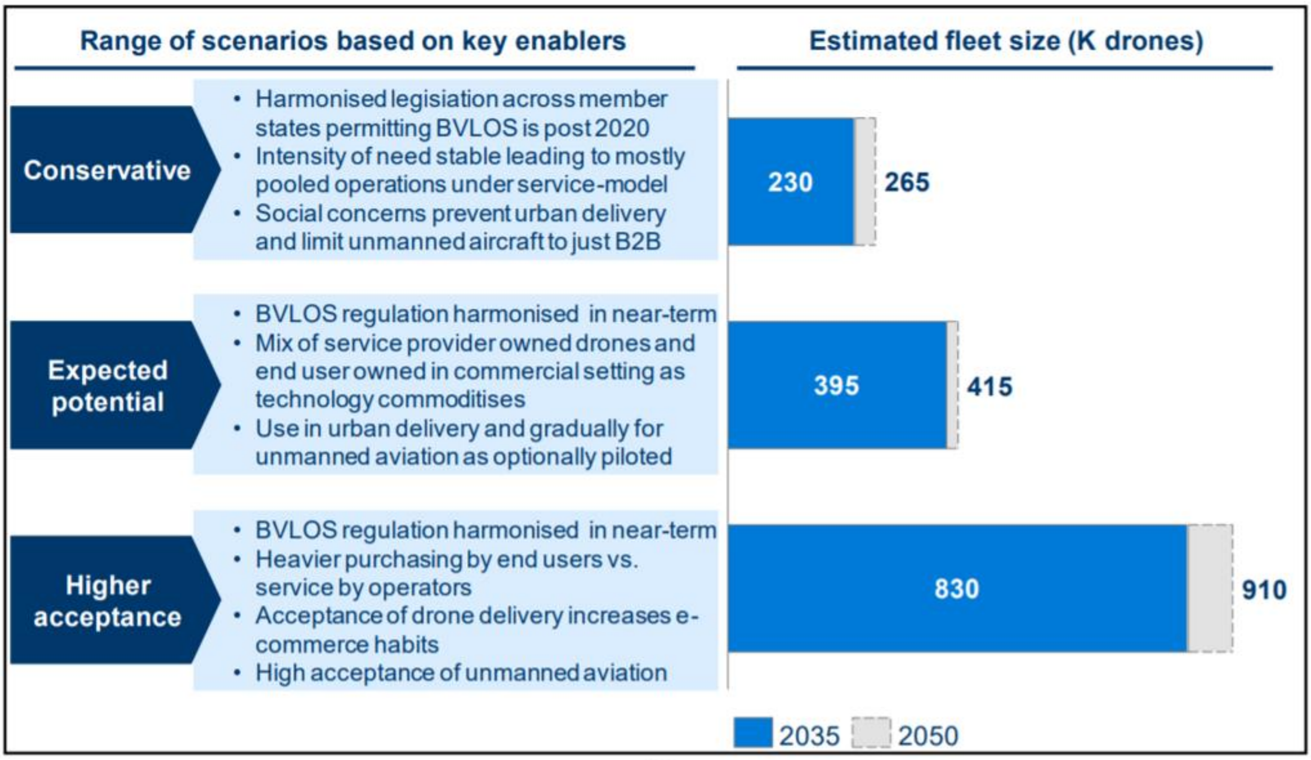


Figure 2 Scenarios for government and commercial demand [3]

SESAR JU *Higher Acceptance Scenario* as of May 2020, proposes the following key enablers that are expected to be satisfied in 2020-2025:

- Harmonization of BVLOS regulation with UTM regulation is planned to come into force in 2021-2022.
- Heavy purchasing by companies has been confirmed in a large study conducted in the US in 2018, which also showed that about 63% of companies that use drone services, develop in-house drone competence, and are not buying it as a service [178].
- Acceptance of drone for packages delivery has increased drastically due to COVID-19 lockdown limitations. In February-May 2020, many drone service companies have offered the delivery of essential medicines and goods with drones. Given that the COVID-19 pandemic is likely to recur, drone delivery is an important solution to movement restrictions.
- High penetration of unmanned aviation has already been achieved by 2020, the use of UAVs is commonplace in all EU Member States.

As noted in the report, the impact of these key enablers is significant, and depending on the (conservative or higher acceptance) forecast can have a quadruple (4x) effect on the estimated fleet size as depicted in Figure 2.

2.1 Trends and Overview of UAV Services

Although analysis of the UAV services market and forecasts for the sale of drones and drone services have started to become more harmonized since 2020, the deviations from the forecasts are still in the margin of 30%-50%. As the market of drone services begins to mature, more data will emerge, allowing for more accurate analysis and forecasting.

The UAV market continues to grow, and consumer-centric innovation is one of the most prominent factors in that growth. One of the most vibrant areas—the global vertical take-off and landing vehicle (VTOL) or the passenger drone market—is likely to be worth US$21 billion by 2035. Automotive and aerospace manufacturers have been experimenting with concepts in recent years, and it is not unreasonable to expect autonomous flying taxis in the skies within the next ten years [4]. An all-encompassing depiction of the sectors and trends for the drone business penetration is provided in Figure 3.

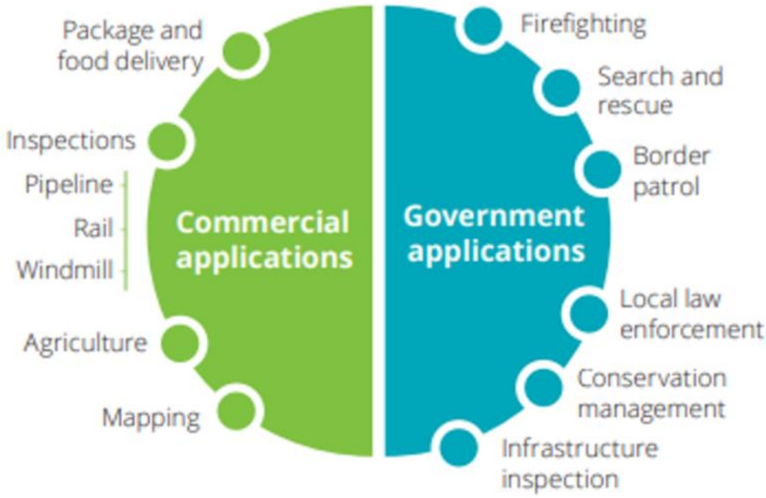


Figure 3 Key trends in drone market [4]

For years, the drone market was in a nascent phase and had yet to break into the mainstream. Then, in 2016, drone industry growth took flight when the Federal Aviation Administration (FAA) granted hundreds of new exemptions for companies to operate drones in the USA through FAA Part 107 [5]. Drone Industry Insights pointed out that Adoption and Automation will be one key trend in 2020 [6].

Meanwhile, across the board adoption of drone technology will continue. As mission complexity decreases (due to higher automation and workflow integration) more companies will start drone operation or pull outsourced operation in. This is reflected in the growing commercial drone market forecast for the next five years. Part of the reason for increased and continued adoption is certainly automation, both in terms of data processing and mission execution. “Actionable Data” is next to a powerful and reliable drone probably the most important driver of the drone industry, as one of our earlier articles showed. Drones often generate large amounts of data – sometimes more than we can handle. The faster, the more accurate, and the easier the images can be evaluated, the better. Further development in AI algorithms can help to reach these goals e.g. by looking at thousands of pictures of wind turbine blades without a human in the loop [6].

In 2018 FAA forecasted that the non-model small Unmanned Aerial Systems (sUASs) (i.e. commercial drones) actual data in the USA far exceeds that trend with over 277,000 aircraft already registered by the end of 2018. Given the accelerated registration over the last year, FAA projected the non-model sUAS sector will have over 835,000 aircraft in 2023 (i.e. end of 5-year period). Important to note here is that 2018 year’s forecasted sUAS for 2022 (452,000 units) will be surpassed sometime towards the later part of 2019 or early 2020 if the present registration trend continues. Starting from a low base of around 13,000 aircraft in 2018, professional grade non-model sUAS sub-sector stands to expand rapidly over time, especially as newer and more sophisticated uses are identified, designed, and operationally planned and flown. If, for example, professional grade sUAS meets feasibility criteria of operations, safety, regulations, and satisfies economics and business principles and enters into the logistics chain via delivering small packages, the growth in this sector will likely be phenomenal. This growth trajectory may even be fur. Because of this wide range in prices between types of sUAS in commercial activities, start-up cost for a business may vary somewhere between $2,500 and $25,000.

Low Altitude Authorization and Notification Capability (LAANC) [7] automated the application/approval process for airspace authorizations. Requests submitted via their enhanced by, for example, the LAANC system, which began authorization in May, 2018. LAANC is designed to allow considerable flexibility in sUAS operations and facilitate non-modelers' use of the NAS. While most of the near-term growth in non-model sUAS will continue to come from consumer grade (over 90 percent), we anticipate a significant part will come from professional grade non-model sUAS as well. As non-model aircraft become operationally more efficient and safer, battery life expands and integration continues, new business models will begin to develop, thus enhancing robust supply-side responses. These responses, in turn, will pull demand forces (e.g., consumer responses to receiving commercial packages; routine blood delivery to hospitals, search-and-rescue operations, etc.) that are somewhat latent and at the experiment stage, at present [8].

Gartner predicts that in 2028, enterprise drone shipments in the USA will total 3.1 million units, rising from 0.2 million in 2018 [9]. The largest segments will be construction monitoring and retail fulfilment, shipping 952,000 and 583,000, respectively, in 2028. Forecast assumptions include:

- To save costs when surveying sites, the number of U.S. construction drones per employee will increase twelvefold between 2018 and 2028.
- Retail drones provide customers with rapid service, so they will increase from 6,100 U.S. retail employees per drone in 2018 to 27 retail employees per drone in 2028.
- To reduce manual tasks, complex drones will grow from 9% of agricultural drone shipments in 2018 to 34% in 2028.
- To survey claim areas at a lower cost, insurance drones will grow from one per 152,000 people in 2018 to one per 6,000 people worldwide in 2028.
- Drones monitor U.S. building health more inexpensively, so their usage will grow from one drone for 470 commercial buildings in 2018 to one drone for 25 commercial buildings in 2028.
- Fire service and police drones investigate incidents without risking lives, so drones will grow from one per 210,000 people to one per 19,000 between 2018 and 2028 [9].

The initial introduction of UAV aircraft to airspace, especially in the commercial world, has been limited to visual line of sight (VLOS) operations. Australia, Canada, China, Denmark, New Zealand, Poland, South Africa, Switzerland, and some states in the US have taken measures to incorporate UAVs into the airspace far beyond visual line of sight (BVLOS) operations, opening opportunities for ever more innovative applications and expansion.

2.2 Commercial Areas

Enterprise Drones (also known as Commercial Drones) hold the most potential in the broader drone market [10]. Business Insider Intelligence defines enterprise drones as all unmanned aerial vehicles (UAVs) sold directly to a business for use in its operations. Under that criterion, Business Insider Intelligence predicts total global shipments to reach 2.4 million drones in 2023 – increasing at a 66.8% compound annual growth rate (CAGR) [5].

As depicted in Figure 4, drone growth will occur across the four main segments of the enterprise industry: Infrastructure, Agriculture, Transport, and Security. The same report also forecasts that Enterprise Drones shipments will reach 805,000 in 2021, a CAGR of 51% [10]. It is important to note that construction, inspection, 3D modelling, etc. all come under the Infrastructure category.

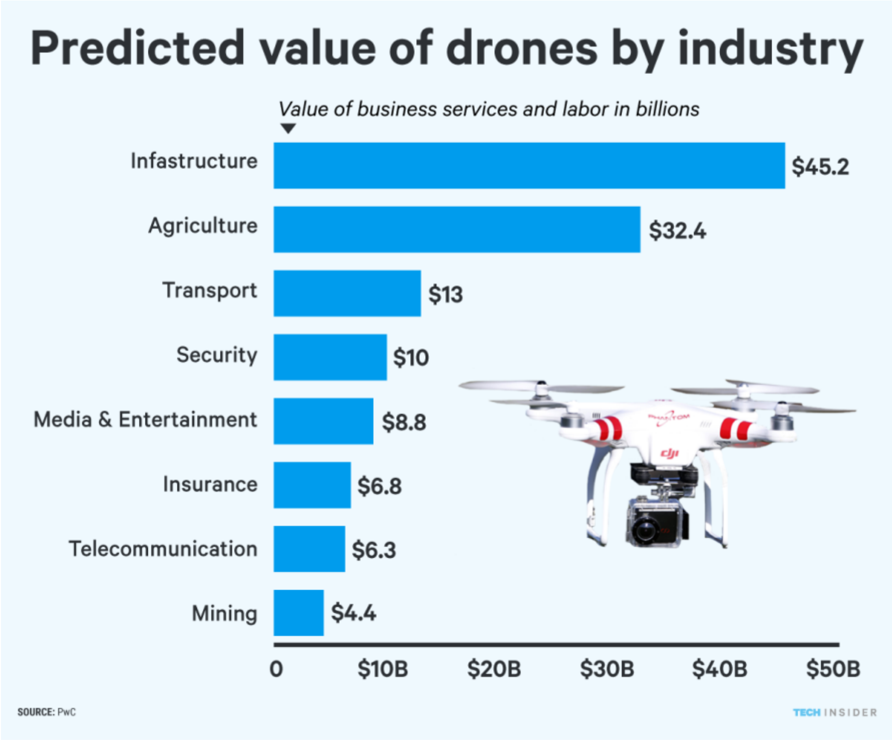


Figure 4 Predicted value of drones by industry in 2030 [10]

In 2018, a survey of 1,700 companies with an annual turnover of at least USD 50 million was conducted in the United States on behalf of Skyward. The main results of the study:

- About 10% of companies used drones.
- About 63% of companies develop in-house drone competence and are not buying a service.
- About 71% of companies, which used drones, spent at least 10,000 USD per year in the field of drones.
- 92% said their company saw a positive return on its drone investment within one year.
- Drone use is on the rise across all U.S. industries, led by the construction and engineering sector with a 35% adoption rate, followed by the federal government's 24% adoption rate [178].

Initially viewed as a military device, drones have established a significant presence in the commercial world over the past five years. The drones and drone services market are anticipated to register a CAGR of 15.37% during the forecast period to reach USD 47 billion by 2025. Enterprise drones are expected to register higher growth during the forecast period compared to consumer drones. Advancements in drone technologies have allowed the manufacturers to produce a wide range of models in different sizes, weights, and shapes that can carry different sensor payloads, making them favourable across a broad application base. However, the lack of regulations and restrictions on the flying of drones beyond the visual line of sight in several countries across the world have restrained the market growth to its full potential. Other factors, like security and safety concerns, and scarcity of trained pilots are also anticipated to challenge the growth of the drone market to certain extent [11].

In 2020, further developments in the drone delivery industry are expected, while passenger drones are likely to trail somewhat behind due to the much higher regulatory and technological toll that they face. More specifically, companies developing passenger drones, (also known as flying cars, air taxis and eVTOLs i.e. Electric Vertical Takeoff and Landing) will need more time and a significant amount of funding to get certified (this process has been estimated to cost around $1 billion per platform).

While the regulation is not a showstopper in the drone delivery industry, access to a combination of reliable technology combined, a nearby expert network and funding (because many small tech companies in the drone delivery sector are totally underfinanced) is currently the biggest challenge.

There are also big regional differences in terms of drone delivery activity and overall UAM progress. While Chinese drone delivery service providers already operate frequently even in urban areas, the US is still in the test stage and struggle with high requirements to operate in public environment. The key to getting ahead now won't just be in governments issuing special permits, but in the set-up of an approval system (such as the Part 135 in the US) which will allow for the scaling of drone deliveries.

The drone industry, more specifically those working in unmanned traffic management (UTM), will prepare for Remote ID standards. Remote ID will introduce the ability of a drone to provide identification information that can be received by other parties. To enable this, the US Federal Aviation Authority (FAA) published proposed a 319-page Remote ID rulebook for public comments in December 2019. In Europe the EASA published an Opinion about Remote ID and their U-Space initiative in March 2020. Remote ID shall avoid the use of ADS-B (Automatic Dependent Surveillance-Broadcast) technology on drones. The FAA is afraid that the high expected drone traffic will negatively affect available ADS-B frequencies, which then will in turn also affect ADS-B capabilities for manned aircraft creating a possible safety risk.

2019 closed off with the announcement of the first ISO approved drone safety standards in December. This means that in 2020 the set-up of a safety management system will be a major regulatory topic. It also means that the foundation for future rulemaking, standardising and legislating of drone operations has now been laid. The key challenge in 2020 will lay in the implementation and harmonization with national standard coordinating bodies and the compatibility of these standards with existing drone regulations [6].

Table 1 and Figure 5 depict predicted value of industry sectors globally in 2030. The aggregated data in Table 1 and Figure 5 are based on the different predictions discussed in this report.

Table 1 Predicted value by industry globally in 2030

Industry	Predicted Value (in $Billion)
Infrastructure and Construction	$45,20
Agriculture	$32,40
Logistics	$20,00
Air Taxis	$15,00
Security	$10,00
Power & Utilities	$9,46
Media & Entertainment	$8,80
Insurance	$6,80
Telecommunication	$6,30
Mining	$4,40

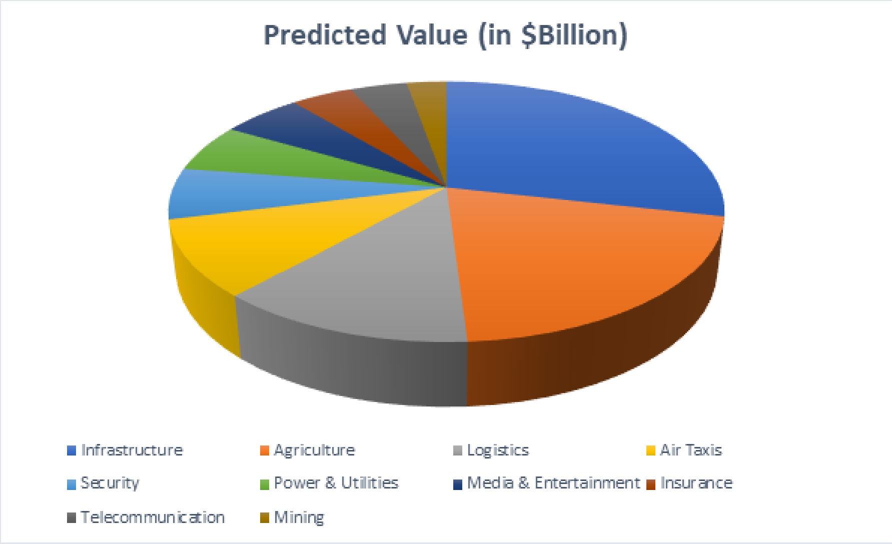


Figure 5 Predicted drone services by industry value in 2030

2.2.1 Infrastructure Inspection and Construction

Tangible assets such as tall buildings or large infrastructures, are difficult to manage and survey, thus, drone utilization for aerial asset inspection services is a very efficient solution. This adds value to the industry by reducing human health risks, avoiding human mistakes, reducing downtime, capturing and transmitting the results in the real time. UAV's will become indispensable for commercial purposes where mission or task can be described as dangerous, dirty, dear and dull (so called 4Ds of robotization). With the promising introduction of the drone technology, such problematic tasks can be managed much more efficiently and safer [12].

Maintenance tasks when undertaken via the traditional methods by technicians impose extremely dangerous manoeuvres on their part in order to inspect such sites. Costs are significantly elevated because of the increased human injury risk parameter and the demanding level of difficulty required for technicians to resolve maintenance issues or technicalities [13]. In this perspective, a UAV assumed inspection, becomes a cost-efficient alternative.

Asset operators and industrial servers are faced with the barrier of increased OPEX (Operating expense) with the utilization of technical, mechanical (equipment) and human capital. Drone inspection technology will gradually alleviate such barriers and eliminate time constraints. The new business model is to capitalize on the effective adoption of drones through specialized operators in a much more cost-efficient manner. In this context, manufacturers, operators and service providers will anchor a competitive edge delivering high quality and increased performance [13].

PwC estimates the addressable market of drones' powered solutions in the power & utilities market at USD 9.46 billion. Drones can live-stream high-definition or infrared video, as well as take detailed high-resolution images, which are later processed to photogrammetry products. For instance, a thermal camera may help identify overheating parts of infrastructure, or spots that require further action. Analysis can be performed on multiple types of infrastructure – e.g. energy towers (poles), water management infrastructure, wind farms and photovoltaic panels [13].

Examples of UAV inspections are evident in the energy industry. Enterprises such as BP, Shell, and Total have taken advantage of drones and now effectively inspect their highly expensive industrial platforms. This is achieved via the integration of drone video, thermal imaging, and image recognition and data analytics. The utilization of these integrated technologies and the time-to-inspect has been slashed (from the traditional conduct) from 56 days to 5 days, which reflects on the high potential of the market to optimize its productivity, resource usage, automate procedures, and subsequently increase

revenues. For example chimney flue inspections entailed business and operational discontinue for several days. Nowadays, such highly demanding inspections can be executed in a few hours through the application of drone technology and can be even more effective thanks to utilisation of 5G connectivity. Most importantly this relieves human risk levels and evidently signifies the technologies imperative and urgent commercial demand reflecting on savings that may reach up to 90% [13].

Figure 6 depicts the savings acquired via the Drone asset inspection technology.

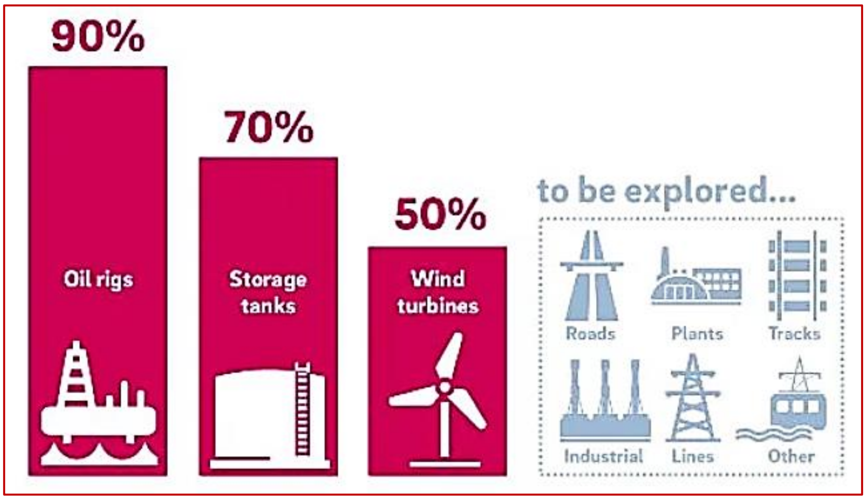


Figure 6 Drone asset inspection savings per infrastructure [13]

Drones-inspections are utilized for power lines, power plants, wind turbines, solar farms and estimation of storm damages. Significant advancement has been noticed in the installation services. In New York, the power authority currently scrutinized the exertion of drone inspection on an ice boom. The traditional cost for such an inspection via the use of a helicopter is normally rated at $3,500 or at $3,300 by employing a boat to carry-out the task. But stunningly the deployment of drone inspectors costs less than $300 [15].

Drones are also used to perform inspection of power lines which spans over several 100s of kilometres. One of the examples of the inspection is a 250 miles of transmission and distribution analysis for power line maintenance and 3D modelling in the United States. 3D modelling, risk analysis of transmission and distribution networks from UAV LiDAR & imagery have proven to be highly efficient compared to traditional methods of inspection, which is usually flying a helicopter to perform inspections [34]. Figure 7 depicts the 3D model acquired by the UAV carrying LIDAR.

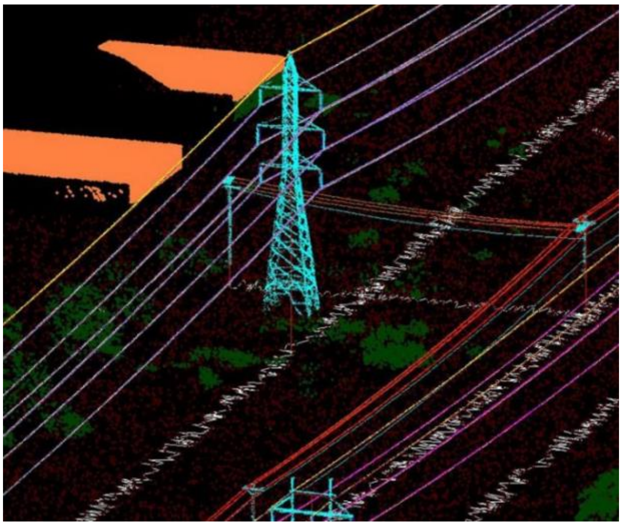


Figure 7 3D model of a power line facility formed by using point clouds using UAV & LIDAR [34]

In another example, a drone was equipped with a thermal camera to perform advanced inspection of power lines. This is shown in Figure 8.

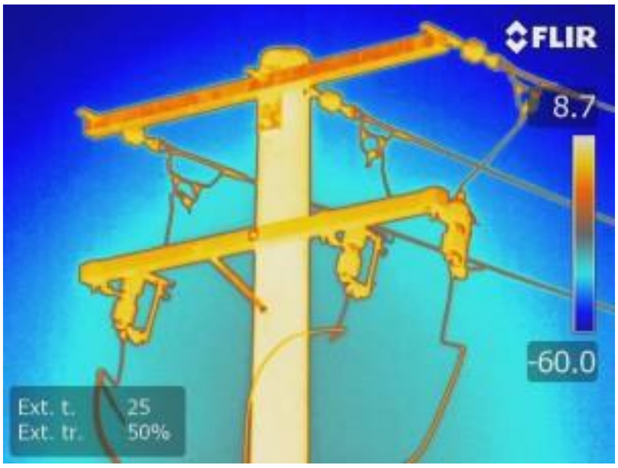


Figure 8 Thermal camera output for power line inspection [35]

Thermal cameras and drones have become a useful combination to perform infrastructure inspection. For example, as we saw before, performing inspection of the power lines using thermal camera has added value.

Monitoring and inspection of power lines have a key role in the grid digitization process, as well as help to reduce electric supply risks and mitigate the impacts of climate crisis. Today, in the era of smart grids, over 90% of network lines are still inspected by on-foot visual inspections. Given the 10 million kilometres of power-lines in Europe, the manual on-foot inspection method is expensive, inaccurate, extremely time-consuming and has a high CO2 footprint. A more accurate and faster method is aerial inspections by helicopters. The main barrier for wide-scale aerial inspection is the high cost – an inspection helicopter hour costs on average €3,500 [179].

Besides power line inspection, there are also other examples such as inspection of solar farms, chimneys, oil refineries, etc.

Further, exemplifying on the drone technology's capacity to improve processes and procedures, AT&T has adopted them to inspect its cell towers, reflecting on safety and securing human lives. The drone program is prepared also by American Petroleum Institute (API). API represents all segments of America's oil and natural gas industry [16]. Drones can help also powerline maintenance by collecting data for precision tree-top cutting purposes. Studies has been also made to extend range by charging drones from power lines [17].

Stemming on these facts, the drone-based infrastructure inspection market acquires high potential to grow. The market for drones in the power and utilities industry will continue to expand at a compound annual growth rate of 23.6%, reaching $515 million by 2030. Digital transformation, remote monitoring and the need to optimise operational costs will drive the significant growth of drone use in the power and utilities industry. It also notes the increasing reliance on drones to ensure the security of power supply facilities. While the current adoption rate of drone technology in the power and utilities sector is less than 10%, the Frost & Sullivan report forecasts a steady increase. Meanwhile, North America is the most advanced regional drones' services market with large utilities in the United States already investing in in-house programs to inspect and maintain their thousands of miles of assets [18].

Because of the adaptation of the drone-inspection technology human accidents in the construction field have been decreased by 91%. The reason behind such development and the increasing demand is the ongoing aging and outdated status of current infrastructures on a worldwide scale. Buildings, industrial infrastructure like bridges, dams, oil rigs and other facilities require regular and frequent inspections, what can be safely and cheaply carried out with the help of drones. Encouraging prospects regarding

the development in UAV asset inspection will bring advancements in battery technology, new fuel consumption, solar, tethering, and gas power towards achieving unstoppable operations. This new standard in asset inspection and intervention provides significant opportunity for those who will incorporate the technology and reap from its benefits towards attaining a competitive edge. In this context, the opportunity in asset inspection is enormous. Shifting the business model toward drone service providers and specialized operators [19].

In the wake of Industry 4.0, many companies have tried to utilise automation and data exchange in manufacturing technologies. This is especially prevalent in the construction industry where the need for increased efficiency and delivering a quality product both, physically and digitally has now become a necessity rather than an indulgence. Many technologies have sprung up to meet the challenge, such as artificial intelligence (AI) and drones. There are several companies that offer highly sophisticated and advanced solutions that are specifically meant for the construction industry. “DroneDeploy”, a cloud software platform for commercial drones has compiled statistics on drone usage based on 100 million aerial images from 400,000 job sites in 180 countries in 2018. Below are some of the findings:

- The construction industry has seen an increase of 239 percent in the adoption of drone technology. The other two industries directly related to construction, namely surveying and real estate, have an increase of more than 100 percent for each industry.
- There are many benefits that are associated with the use of drones in construction, namely increased safety, cost saving and better data collection and usage.
- Drones are primarily used for progress tracking and communication, preconstruction and site planning, quality control and assurance, bid process preparation and job site risk mitigation.
- 55% of DroneDeploy customers report increased safety as a result of implementing drones [27].

A typical commercial construction project runs 80% over budget and 20 months behind schedule [28].. This inefficiency presents a massive opportunity for drones in construction, as 3DR’s CEO Chris Anderson has pointed out [29]. “On-screen, in the architect’s CAD file, everything looks perfect. But on-site, in the mud and dust, things are different. And the difference between concept and reality is where about $3 trillion of that $8 trillion gets lost, in a cascade of change orders, rework, and schedule slips. Drones are meant to close that gap.” – Chris Anderson, CEO 3DR [30].

In 2015, the construction company Komatsu launched Smart Construction, a drone-assisted, automated equipment service intended to alleviate the burden of the country’s severe shortage of skilled workers. Smart Construction combines Komatsu’s intelligent Machine Control (iMC) technology with jobsite surveys provided by drones and 3D laser scanners with the goal of completely automating pre-foundation work. Since then, the service has grown quickly and has been used on more than 5,500 Japanese jobsites in 2018. Komatsu proceeded with the biggest single purchase of drones in 2018, when bought 1000 DJI drones [31] and is expanding activities in Europe in 2020 [32].

The construction industry utilizes drone hardware, software and also additional capabilities such as 3D mapping and surveying. A sample of a 3D modelling used in the construction industry is shown in 9.

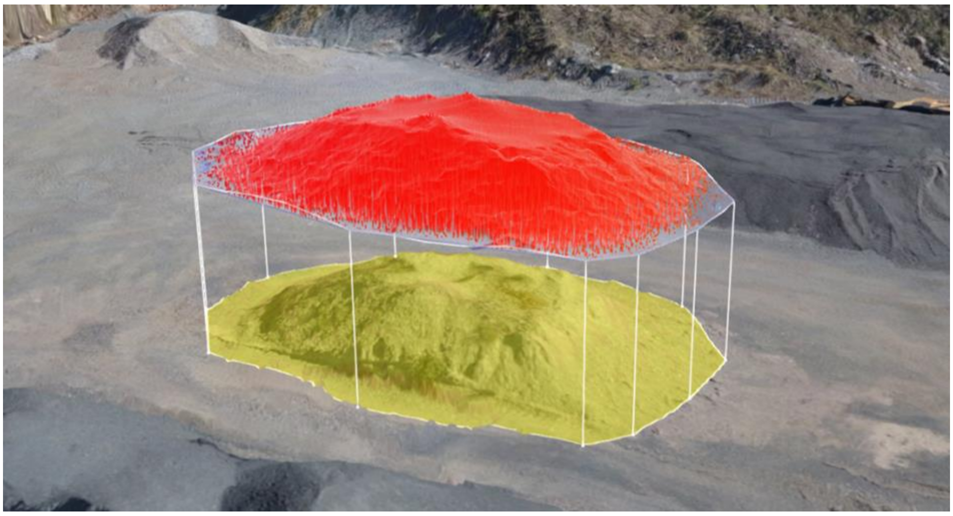


Figure 9 Sample of measurements made using 3D models in the construction industry [186]

Figure 10 A 3D model of Aalto University [33]

Figure 10 shows a 3D model of Aalto University formed by images captured while flying a drone over the area. In [33] is devised a new method that involves taking aerial photographs of an area with a drone, which can be used as models to design radio links. Using the photographs and software that transforms 2D objects into 3D images models to design radio links. The measurements and simulations we performed in urban environments show that highly accurate 3D models can be beneficial for network planning at millimetre-wave frequencies [33]. This example clearly demonstrates how drones are used to form 3D models of infrastructures which can further be used to deploy 5G network.

In terms of the adoption rate in the industry, the chart in Figure 11 shows that the construction industry has the highest rate for adopting drones into the market [38]:

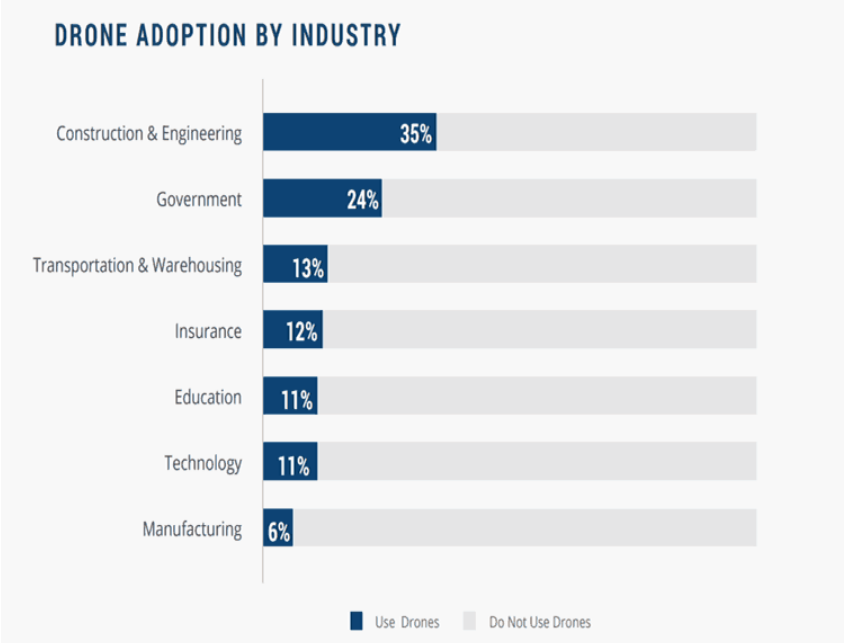


Figure 11 Drone adoption by industry [38]

2.2.2 Agriculture

Agriculture and forestry are considered as the fastest growing and second biggest UAV business area. In the near future, automation levels will get higher and more data will be collected once sensor technology evolves and sensor prices are cheaper. For example, hyperspectral cameras are now expensive and heavy, but they are getting cheaper every year [20].

Drones assist in sustaining well crop conditions and overall improve performance with the limitation of existent farmer resources. Agricultural precision in line with drone technology incorporates systems such as geo-tagged images, equipment performance and management data. The ongoing increase in the global population is projected to increase by 25% by 2050, reaching a total population of 9.2 billion people as denoted by the "United Nations Food and Agriculture Organization" [21]. This fact consequently reflects to the increasing demand in food production and supply estimated to reach an increase of 70% by 2025. These statistics constitute the drone technology and its development for agriculture purposes a critical aspect in the normalization and coverage of such demand. In this perspective, the market is predicted to grow expeditiously in high rates.

Drones utilized for agriculture fields that are below 50 hectares are relatively much more affordable in imaging compared to manned scouting, manned aircraft surveillance, and satellite imaging. They achieve greater precision, detect shades, plant temperature and humidity levels. Most importantly with drone specialized agriculture practices, issues concerning land and crop are addressed, while production rates/volumes are leveraged, and expenditures deduced [22].

Agricultural UAV's are utilized to record the number of plants, their height and health (yield monitoring, plant stress monitoring, leaf area indexing, tree classification etc.). In addition, they collect data on the presence of disease, nutrients, weeds, estimate biomass and identify piles, patches and other suspicious landscape threats. After pesticide or fertilizer recipes made based on the data collected by drones the drones can even be used for precision spraying [23]. Research indicates that agriculture drones could conserve up to 90% of water usage for irrigation, and 30% to 50% in chemicals for crop spraying. Drones are from 40 to 60 times more efficient than manual labour, which can be translated as up to 5x faster than tractor application of pesticides [24].

The agriculture drones' global market is expected to grow from USD 1.2 billion by 2019 to USD 4.8 billion by 2024 at a CAGR of 31.4% as depicted in Figure 12.

Figure 12 Global Agriculture Drones Market prediction 2019-2024 [185]

The pressure on global food supply due to growing world population and increase in venture funding for the development of agriculture drones are a few of the key factors driving the growth of this agriculture drones' market. Agricultural drone services are supported by exemptions from civil aviation authorities for the use of agricultural drones in situations that are often not allowed in densely populated areas (e.g. BVLOS flights) and high adoption of aerial data collection tools [25].

The above factors direct us to the dynamic of the drone 5G technology within the agricultural sector, its adaptation and contribution to the current international commercial market but also its future potential for repetitive market growth and emerging opportunities for service providers and consultants in the field. Examples of new markets and business opportunities include niches such as drone service providers that specialize in data tracking for crop management consultation. The emerging niche and need reflect on the fact that 56% of the workforce is over 55 years old with a lack in digital knowledge and computer software management skills [26].

Drone technology is gradually replacing services delivered by satellites, manned aerial aircraft, ground machinery and manual labour. While, the efficiency of the drone technology increases productivity by optimizing landscapes and crops and reduces operational inputs such as labour. The application of drone technology for agricultural purposes provides efficient and effective crop management reducing significantly natural and physical resources such as water, chemicals and labour hours, which consequently lead much quickly to a breakeven point in terms of ROI over the outdated traditional agriculture methods [21].

While in the infrastructure inspection sector, drones are used in the remote sensing function, in agriculture UAVs are also used for physical work - planting seeds and spraying fertilizers and pesticides [183].

2.2.3 Drone Logistics

The drone logistics market has been estimated to be 29 billion USD by 2027 with CAGR over 20% from 2022 to 2027. This prediction includes drone logistics and transportation market solutions for warehousing, shipping, infrastructure, software, both in the commercial and military sectors. This prediction includes freight drones, passenger drones, and ambulance drones [36]. Currently, there are commercial parcel delivery drone services in different countries. Zipline delivers medical items to rural areas in Africa. In the Europe the most known commercial drone parcel delivery activity is by Matternet and Swiss Post transporting laboratory samples in Switzerland. Food delivery services with drone have

been piloted in Reykjavik by FlyTrex and in Helsinki by Wing [39]. North America is projected to be the fastest-growing market for drone logistics during the forecast period.

The drone logistics and transportation market in the North America region is projected to grow at the highest CAGR during the period 2022-2027. This growth can be attributed to the high demand for UAVs from the commercial and military sectors of countries in the region, such as the US and Canada. Key players operating in the drone logistics and transportation market include PINC Solutions (US), CANA Advisors (US), Drone Delivery Canada (Canada), Matternet (US), and Workhorse Group (US) [36].

There are about 50.7 billion parcels delivered every year in China, and nearly 80% of them weigh less than 2.27 kilograms which represents great potential for drone delivery [40].

Drone logistics can be divided to different categories by the parcel weight. Currently, commercial operations are focused on less than 5 kg parcels within less than 15 km distance. There is no commercial activity at the moment for heavier parcels. Business opportunity for heavy logistics is interesting, especially in rural areas, where delivering logistic with delivery truck is expensive and produce significantly CO2.

Drone logistics can be categorized also by the delivery means, as graphically depicted in Figure 13 Drone delivery use cases depiction [181]

Most common category these days is parcel delivery from business to consumers. In this category, drones will deliver parcel on demand to the consumer and either lowering the parcel via cord or by landing and releasing the parcel. Some companies like Zipline are using parachutes to deliver the package, although this delivery method may not be feasible in tightly populated areas, such as in the cities. After releasing the parcel, drone will fly back to the drone terminal for the next mission.

Second category of the delivery is services where a customer can send parcel. In this category, drone will land and customer will attach the parcel to the drone and drone will fly to the destination. This kind of delivery will be feasible in business use, where fast delivery from company is required and training is easy to arrange for the personnel.

The third category is Hub-to-Hub deliveries. In this category, consumer or personnel will leave parcel to dedicated landing hub, where drone will pick it up. Drone will fly to the destination designated by sender and releasing the parcel to the same kind of delivery hub. Receiver can then pick the parcel from delivery hub.

The fourth category is focusing on last mile in the delivery chain. In this category parcel deliver drone will take off from delivery truck/van and deliver the parcel to the destination. This kind of delivery option has not been yet piloted, but example Matternet with Mercedes-Benz and Workhorse Inc are developing this kind of systems. Especially this kind of solution is interesting in rural areas, where the delivery truck needs to deviate from distribution route to deliver parcel to the private house and deviated route can be many kilometres.

There is also some research done for drone delivery, where drones will load delivery trucks or vans. This solution is interesting in cases where the logistic terminal is located in congested areas. In this solution the delivery drone will bring a parcel from terminal to the ground vehicle.

The last delivery category is intercity parcel deliveries. Currently, there are few start-ups developing long range drones capable to carry over 100 kg parcels. Now, these technologies are expensive and for current costs, there is not solid business case behind. However, during the next 30 years the time spent on this kind of UAVs will be more common.

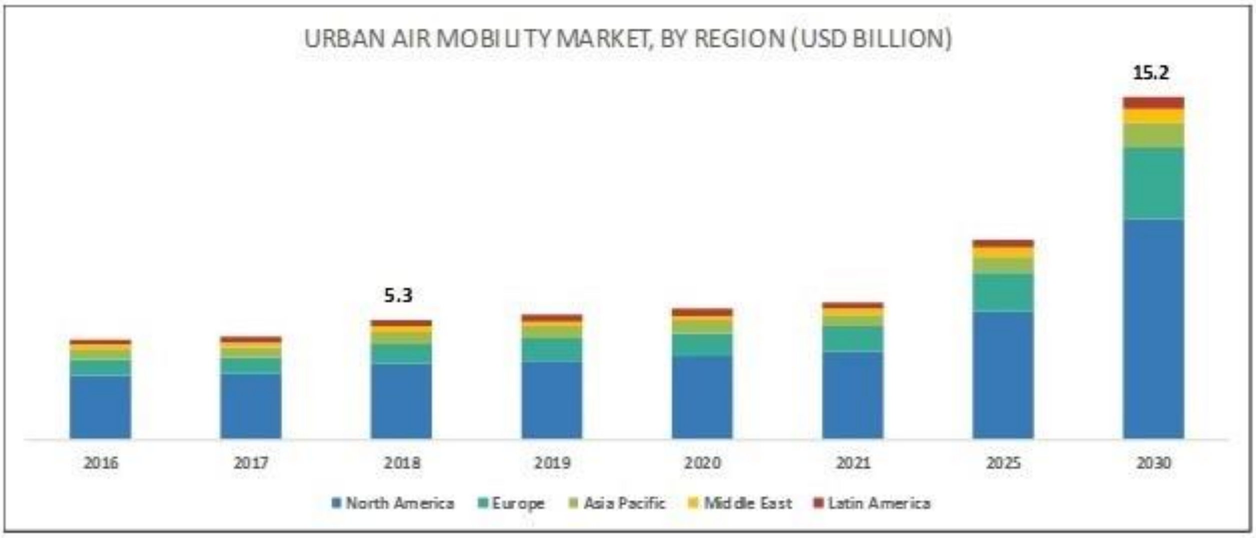
At the moment, the current trend is that parcels less than 5 kg are delivered to consumers, with the system where the parcel is lowered down with a cord, and parcels more than 5 kg are delivered to trained personnel by landing the drone and letting the trained staff release the package. Heavy logistic will require more time as these technologies are still expensive [180]. Figure 13 shows the evolution of drone logistics in next years.

Figure 13 Drone delivery use cases depiction [181]

Most of the drone logistics flights will be BVLOS operations. BVLOS operation bottleneck for safe operations is connectivity. To assure good signalling for Command and Control (C2) and telemetry, most of the drone logistics solutions are using mobile networks. Therefore, 5G will be a promising technology to enhance safe connectivity and may help to provide new safety features for drone logistics operations [41].

2.2.4 Drone Taxis

There is a great hype on drone taxis. There are billions of dollar investments for vast number of start-ups. Also, all big companies such as Airbus, Toyota, Uber, etc. have their own plans for drone taxis or Urban Air Mobility focused on Air taxies. Market prediction is $15billion by 2030 as depicted in Figure 14 [42].



Source: MarketsandMarkets Analysis

Figure 14 Urban Air Mobility market by region [186]

A critical point that enhances the transfer and preference towards drone transport is the fact that executives strongly consider that by 2025 almost 50% of consumers will not want to own a car. These operational prerequisites are fundamental for a wide fleet of commute mediums such as drones, which in turn shall solve urban traffic issues with efficient time-to-reach destination for urban commuters. The Chinese firm, “Ehang”, has undergone over 1000 flights at a 300-meter vertical height and loaded over 500 pounds with human passengers on-board. At the same time, it is estimated that gradually the cost of transport per mile could be reduced up to 40% via the utilization of the different available interconnected forms of transport including drones [43].

Taxi drones will initially face many challenges such as high production cost but despite this temporary barrier, investors remain attentive to the technology and are drawn by the sector and its potential and capacity to thrive. Air mobility remains top priority for many corporations (such as Volocopter and Ehang), who are specializing in drone production and related supportive technologies such as air traffic management [180].

Adding to the complexity of the technology and its components another limitation is the increased cost of urban landscapes. A concern that arises is the fact that parking/land stations must be developed possibly on large buildings. Such tangible assets (buildings) must exceed by much the height of the existent formerly installed energy power lines to avoid collision or another solution could include their in-ground reinstallation, for those countries that have not yet implemented such advanced energy modifications. In addition, it is vital to scrutinize in urban areas if the accessible amount of land stations (landscapes/buildings) are available and if they are feasibly suitable for construction or renovation considering the provisional strict regulatory assemble specifications in order to cover the demand of a new established and continuous growing Drone fleet [44].

In this context, UAV technologies and its relevant quadrants must be well designed and integrated in to the air mobility ecosystem such as architectural aspects, supportive technologies, airspace allocation, Beyond Visual Line of Sight (BVLOS) flights and of course, standards involving Advanced Aerodynamic Vessels (A2Vs) carrying human passengers, collision avoidance, autonomous situational awareness and most importantly a unique precise direct geo-referencing infrastructure for UAV's that eliminates human mistakes and ignorance. The status of such technologies remains at an early stage that requires advancements in tamper proof localization, mapping but also the integration and modification of the existent systems and infrastructure [45].

Despite the ongoing research in the field and its conventional early stage, "Uber Air" considers that UAV's (VTOL's) will bring new added value as commute time will be reduced significantly and journeys will be completed in a fraction of the time in comparison to today's transport mediums. Uber predicts that in due time, its UAV's can be offered at similar costs to that of its current car ride-sharing unit costs. The cost will be initially higher, estimating that the service will cost roughly $5.73 per passenger mile at launch. But the cost will gradually fall to $1.86 before ultimately reaching $0.44 per passenger mile as the technology matures. Similarly, representatives from the passenger drone company LiftAir estimate that a 10-mile trip will cost $20. These facts signify the potential of the market and the disruptive Drone technologies capacity to modify the existent forms of commute, but it is critical to speculate and distinguish an interim point that binds and addresses all those elements and pre-conditions that are essential for the Air Mobility ecosystem [46].

2.3 Governmental Areas

Drones are increasingly being used by government agencies. Figure 15 gives an overview of the status of commercialization by different governmental fields. The most common applications under the governmental areas are the drones used by the police, search and rescue, emergency response units such as pandemic relief.

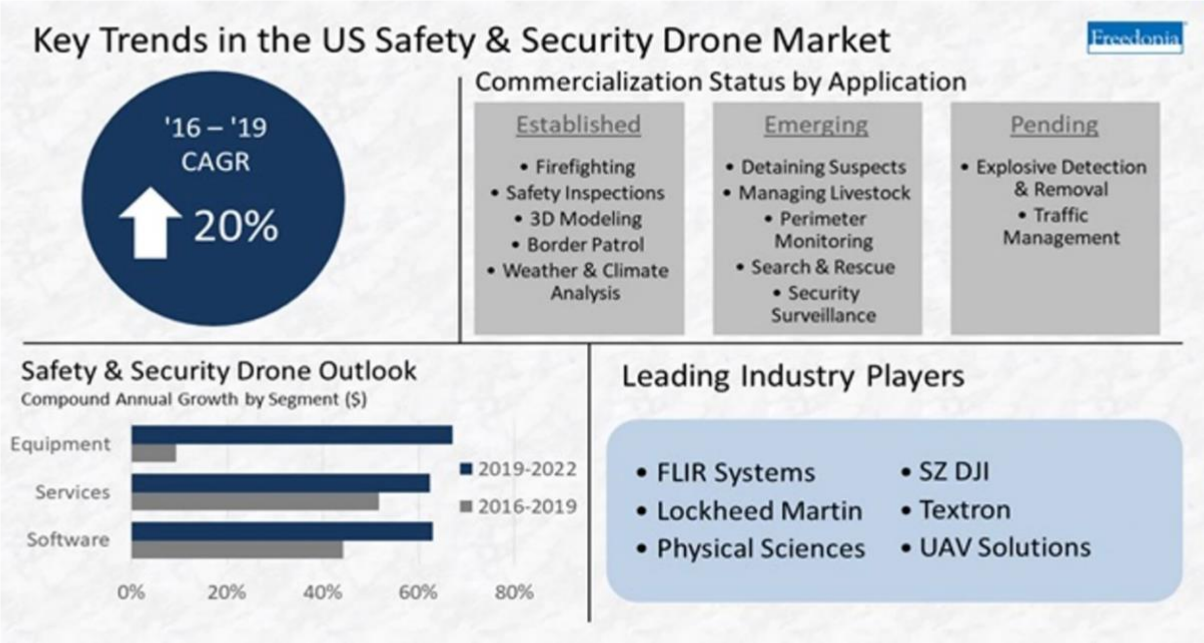


Figure 15 Key Trends in the USA Safety and Security drone market [47]

Bard's Center [65] for the Study of the Drone released the third edition of its Public Safety Drones report. The new edition finds that at least 1,578 public safety agencies in the US now use drones, up from 910 when Bard released its second edition in May of 2018. (The "at least" is because the report doesn't include public safety agencies, such as those at the federal level, with undisclosed drone programs.)

The numbers in the three reports paint a picture of extreme growth on the use of UAVs in the field of public safety:

- 1st Report [66] in April, 2017 - 347 agencies
- 2nd Report [66] in May, 2018 - 910 agencies (+162%, or 43 new agencies/month on average)
- 3rd Report [67] in March, 2020 - 1,578 agencies (+73%, or 30 new agencies/month on average)

Although adoption has slowed somewhat between the 2nd and 3rd editions relative to the explosion we see between the 1st and 2nd, there is still a clear trend of growth.

While drones bring many benefits to law enforcement and security teams for ensuring public safety, they also carry their own set of challenges:

- The challenge of managing the vast amounts of data that drones produce. While drones can lower the costs of data collection, public safety officials must then determine how to effectively manage it. The result is all-too-often data overload, wherein valuable information becomes a burden due to poor organization, distribution or storage.
- Public perception of drones (and public surveillance in general). The subject has proven to be nothing if not controversial. Some civil liberties groups are concerned about what will happen to the data that drones collect. If citizens aren't given good answers to questions around data privacy, public relations hurdles could slow down the pace at which public safety institutions are able to innovate on this technology.
- Regulatory barriers. Several states have passed "drone legislation" which regulates their usage [67].

In the European Union, the General Data Protection Regulation (GDPR) requirements for the handling of information collected by the drone must also be noted.

2.3.1 Police

In the USA a police helicopter costs from $500,000 to $3 million to acquire, and $200-$400 an hour to fly. The average training time for a civilian helicopter pilot is between 40-50 hours. Most people can learn to fly a GPS-stabilized drone within an hour. The setup time to deploy a drone is only a couple of minutes [48].

The drones are quieter – and less expensive to run – than the police helicopter. The noise volume is similar to that of a large fan. The drones will be used for short periods of time, usually about 15 minutes to minimise any noise concerns [49].

In Finland up until January, 2020 over 400 police officers have been trained to operate drones and more than 200 of the aerial vehicles are in official use. Drones are most widely used by police for documentation, in searches and for situation analysis. Forensic investigators use them to gather data by recording crime scenes. They are used to track fleeing criminals and supply information how to catch lawbreakers. Over the past three years, police have used drones in management and security operations involving large public gatherings, such as events during Finland's Presidency of the Council of the European Union and during Independence Day celebrations. Finnish Police rely on ordinary supermarket drones because they have an unfailingly good cost-to-quality ratio [50].

The New York Police Department unveiled plans to deploy fourteen (14) of the unmanned fliers and to train twenty nine (29) officers to operate them. Eleven of the devices are Mavic Pro quadcopters, two of them are M210 RTK quadcopters, and a DJI Inspire quadcopter for training pilots. More than 900 law enforcement agencies currently use them. The Las Vegas police have used them to monitor New Year’s Eve festivities on The Strip. The police in Cleveland have used them to pursue suspects [51]. Chula Vista police department belongs to San Diego UAS IPP (Integration Pilot Program) which is one of the nine selected UAS IPP programs in the US. Drones has helped to save resources a lot as depicted in Figure 16. Public acceptance has been become good by making operations as transparent as possible (e.g. citizens can see flight routes afterwards and have means to comment operations) [52,53].

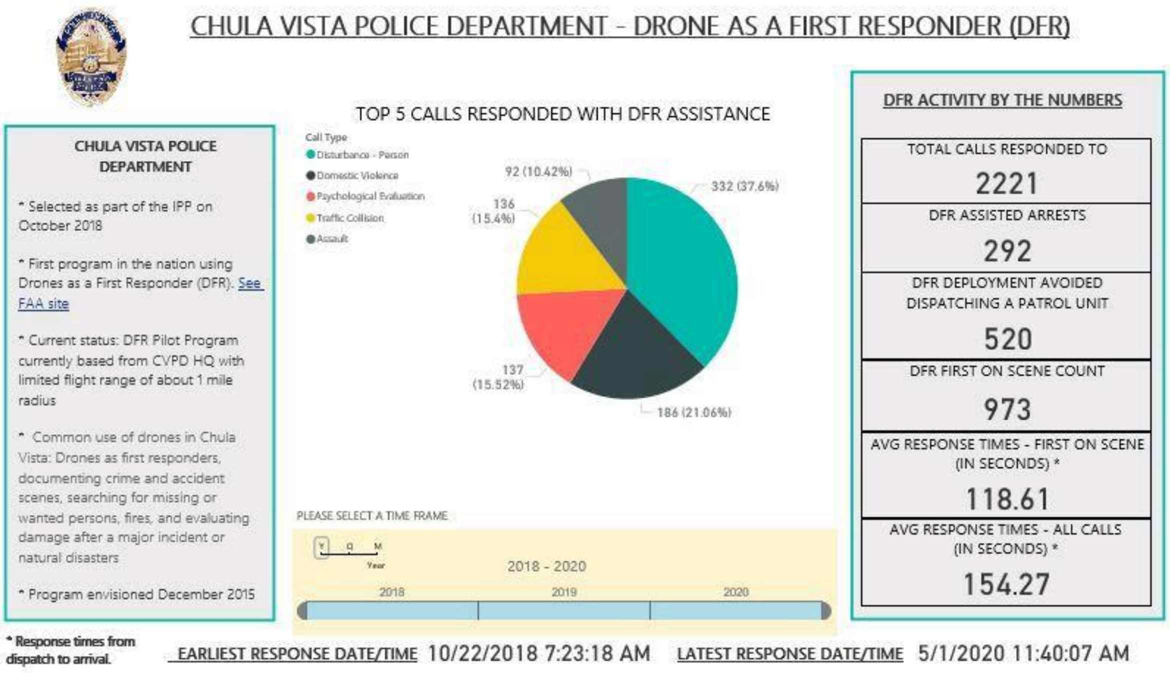


Figure 16 Chula Vista Police Department drone statistics 2018-2020 [155]

Drones will be used for:

- Assistance with searches for missing people,
- Assistance with investigations into road traffic collisions,
- Investigation of major crime incidents and Industrial Accidents,
- Assistance with event planning and management,
- Situation awareness for Officers and Commanders in a variety of policing incidents.

Drones will not be used for general patrol/surveillance. Current drones cost about £1500 for the basic model [54].

2.3.2 Rescue

Drones have already been used to assist in search and rescue operations from as early as 2017 [55] However, the range and functionalities of these drone operations have been limited due to lack of a high-speed, reliable communications network. With the advent of 5G, governments and disaster relief organizations will use 5G-connected drones to aid in emergency efforts. Drones in the sky will communicate and share real-time data with each other and teams on the ground, increasing the speed and effectiveness of search and rescue missions. Based on real-time analysis of structural damage and debris levels, relief managers can quickly dispatch rescue teams who would be able to coordinate efforts more efficiently armed with the information provided by the drones. As technologies advance, swarms of autonomous drones deployed remotely over 5G will be able to enable assist in remote search and rescue operations.

The value of the drones for search and rescue teams really shows in three main areas:

- Responding quickly at a low cost.
- Allowing the use of sensors such as thermal imaging and zoom cameras.
- Providing automated search coverage of a precise grid.

With the enhanced Mobile BroadBand (eMBB) capabilities of 5G technology, thermal and visual sensors installed on drones such as DJI Inspire 1 and DJI Matrice M210 [56] will be able to stream real-time data to the MEC/Edge-based application allowing algorithms to analyse the feed and detect people under almost any condition.

Drones are increasingly being used to support the public safety and first responder community. Drones offer low-cost, easy to operate, and analytically sophisticated remote sensing solutions in search-and-rescue (SAR), structure fires, hazmat response, wildfires, medical supply delivery to remote locations, and many more. The European Emergency Number Association (EENA) organize Drone Efficacy Study which conducted by DJI in 2017. The final recommendations of this study focus on creating drone-enabled SAR tactics; developing specialised and standardised training for pilots; running optimisation tests to understand what is the best combination of aircraft, payload, technology, tactics and training; and validating all of them with rigorous research like Randomised Control Trials [57].

In 2019 Sendai City (Japan) and Nokia successfully conducted a test flight of a Nokia drone on a private LTE network provided by Nokia Digital Automation Cloud. They tested the potential use of drones during a tsunami or other disasters to help in prevention and mitigation efforts. The test verified that using a private LTE network to control and communicate with the drones is an effective means for enhancing situational awareness and communicating with the affected population during a disaster. This is the first time in the world this type of trial has been conducted [58].

Italian National Fire Corps (CNVVF) use drones since 2010 based on following reasons:

- To avoid or to reduce risk exposition of firefighters

- Operative costs are lower than traditional aerial vehicles
- To increase efficiency and effectiveness in rescue operations, taking advantage of a «different» point of view in order to optimize planning

CNVVF used drones effectively for Genoa Bridge disaster rescue operation on 14.08.2018 as depicted in Figure 17.

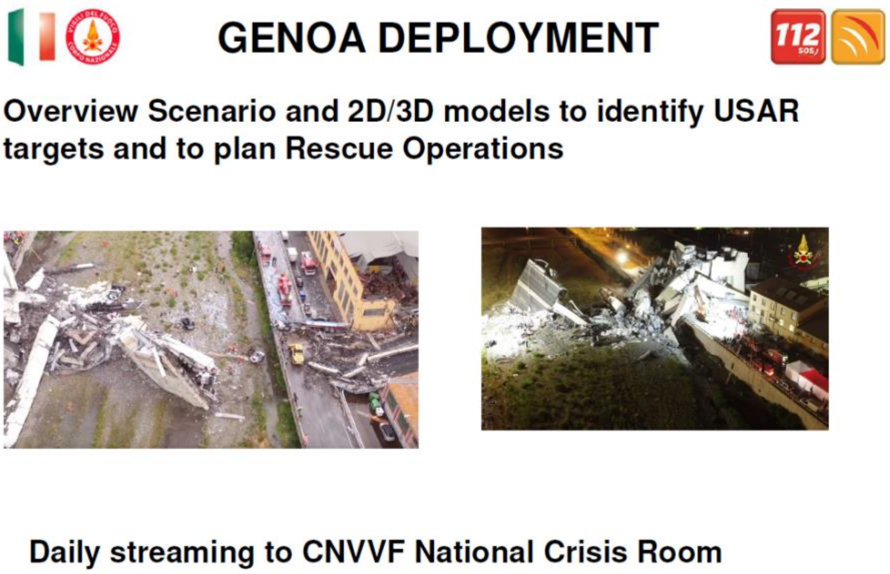


Figure 17 Deployment of UAVs during the Genoa bridge disaster rescue operations 14.08.2018 [167]

2.3.3 Drones against Pandemic Diseases

Since February 2020, drones have been actively used in China [160], Spain [158], France [159] and the US, to fight against the spread of COVID-19, a coronavirus pandemic.

In other parts of China, drones were used to deliver masks, groceries, and other essential supplies to quarantined families. Chinese officials also used drones with chemical sprayers to disinfect sidewalks, market alleyways, and other public spaces [161]. Drones have also been used to survey and map specific provinces in China to enforce the world's biggest quarantine [162]. Finally, in China drones were also used for delivering test samples [163].

In China, agricultural drones, designed to spread fertiliser, have been repurposed to spray disinfectant across pavements and public squares, as well as deliver groceries to remote island communities. Drones have also been used to deliver test samples, dramatically cutting journey times. Figure 18 shows a real use of drone spraying disinfectant in streets of China [62].

Figure 18 Airborne response for COVID-19 a drone sprays disinfectant on streets in China's Hebei province [62]

In Spain, the police have used drones to warn people to stay at home. These drones controlled by pilots have used a radio installed on-board to relay warnings to desert public spaces and return to home [164].

Likewise, the French police have deployed drones over Nice's city centre and main roads to urge people to comply with the lockdown measures [165]. Excerpt from an article published by The Guardian shows the reality in which the use of drones have sky-rocketed during the pandemic situation – "In France, the police have started using drones to help enforce its lockdown, monitoring parks and public spaces to make sure people are not leaving their homes for non-essential trips, while, in the UK, Northamptonshire police are planning to increase their fleet of drones, which will be equipped with speakers to transmit public information messages and tell people to get back indoors. No nipping out to get those non-essential items, now – the drones are watching" [62].

In Belgium, which had more than 50 thousands of COVID-19 cases, authorities have begun using drones to warn citizens about a lockdown that was put in place [153]. Drones could be seen hovering overhead and reading off medical guidelines to people below.

Police departments in California in the US are using drones equipped with cameras and loudspeakers to monitor and enforce a coronavirus shutdown [152], in some cases doubling their fleet of drones and using also night-vision cameras. In the state of Connecticut in the US, the police department has started exploring the use of drones for pandemic situation control. According to the Westport Police Department and the town's top elected official, First Selectman Jim Marpe, the goal is to use the technology as part of a pilot program to "flatten the curve" of the pandemic. In collaboration with Draganfly, the company that developed the drone, the technology can detect fever, coughing, sneezing and heart and respiratory rates, and that Westport police plan to use it to protect those considered high-risk, such as senior citizens, and monitor people gathering in crowds, including to see if they are maintaining social distancing [61].

Several other countries have started using state owned drones for monitoring the situation, making announcements, and also for general surveillance of the situation [154], [156], [157].

The drones were used to measure people's temperatures as they walked through public spaces in an effort to identify individuals with high temperatures. Software being developed at the University of South

Australia in conjunction with Canadian drone manufacturer Draganfly could see drones used to monitor the health of people, including spotting sneezes and tracking whether they have a fever. The device uses thermal cameras and artificial intelligence to measure some of the indicators of coronavirus in groups of people: heart rate, body temperature, coughing and sneezing. According to Professor Javaan Chahl, the camera from the drone measures subtle change in skin tone that is associated with heart beat. This technique is called Eulerian Video Magnification (EVM), which monitors movement we can't detect just by looking at someone. It was originally developed by a team of scientists at MIT's Computer Science and Artificial Intelligence Lab and has a number of applications beyond heart rate detection. Figure 19 shows an example of how drones are used to detect fever or elevated temperature in humans by using a thermal camera on a drone [59].

Figure 19 Temperature of a human being detected by a thermal camera on a drone [60]

2.4 5G!Drones Use Cases Areas

The main aim of the 5G!Drones project involves executing UAV vertical use cases on top of 5G facilities. Other objectives include the validation of 5G KPIs for use cases, and the evaluation of the performance of different UAV vertical applications. 5G!Drones puts significant strain on the UAV requirements and aims at allowing 5G facilities where UAV vertical industry use cases can be rigorously tested and evolved), to improve products and services.

Relying on the expertise from 5G!Drones vertical partners and supporting industry partners, several use cases have been identified which reflect key UAV applications covering civilian and commercial scenarios for which 5G is highly needed. The business areas of the 5G!Drones use cases, which are implemented and tested using in the 5G facilities, are presented and analysed in the next sections.

2.4.1 UAV Traffic Management

This 5G!Drones use case area (depicted in Figure 20) will demonstrate a common functionality for all UAV applications, by providing the necessary safe and secure incorporation of drones into the air traffic. Indeed, the dramatic growth of UAVs over the past decade and the subsequent development of commercial drone activities especially at low altitude have posed the question of drones' safe and secure flight operations in the face of increased air traffic. UTM (UAV Traffic Management) is expected to manage drone traffic in the lower altitudes of the airspace, providing a complete and comprehensive end-to-end service to accumulate real-time information of weather, airspace traffic, drone registration, and credentials of drone operators, among others, fully aligned with the expected impact that UAV sector aims to create to all involved stakeholders.

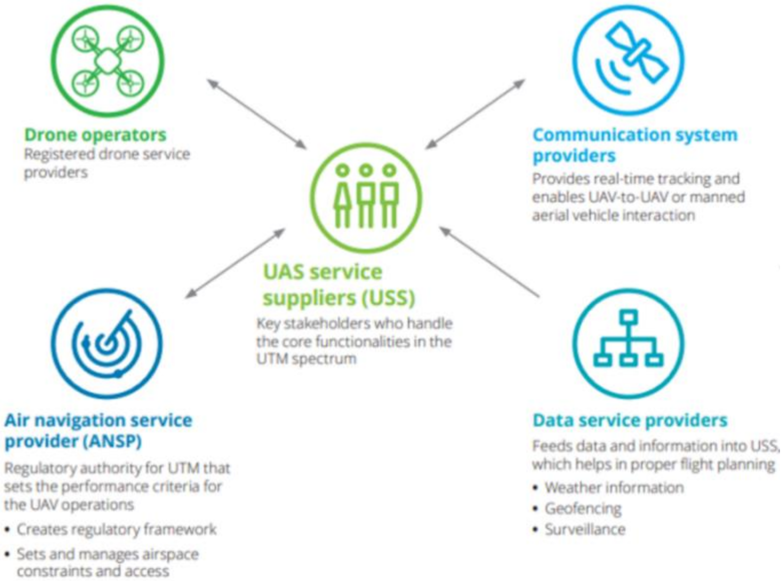


Figure 20 Unmanned Traffic Management (UTM) Key stakeholders [63]

The need for UTM systems has been driven by a number of factors such as the recent increase in the number of drones in the airspace, increasing involvement of different governments and emerging regulations, as well as collaboration of key stakeholders for the development of a working architecture. Furthermore, public security and safety concerns, privacy concerns, and vulnerability to cyber-attacks are some of the major challenges to the adoption of the UAS traffic management systems. Also EASA has in March 2020 proposed the world's first urban drone traffic management rules, with the aim to ensure safe operations, while also creating the basis for a competitive U-space services market, and establishing a level of environmental protection, security and privacy that is acceptable to the public [103]. There is a growing body of research dedicated to resolve a diverse set of challenges pertaining to drone operations, which will fully be taken into consideration. It should be noted that drone applications will require extremely low end-to-end latency, in the order of milliseconds, in order to operate in a safe and secure way.

The UTM system should enable UAS (drone) operators to check flight possibility in a given area, digitally submit a flight plan and obtain permission to fly if it does not threaten the safety of other space users, especially aircrafts. For traditional air traffic controllers, UTM provides information about drone flights planned in the vicinity of international airports along with simple authorisation/non authorisation tools. The air traffic controller would have also dynamic geofencing tools and can create alert zones which would order drone pilots to bypass or land in a given area. The UTM system should also provide fast, digital, non-verbal communication between air traffic controllers and drone operators during the drone operations.

From drone operator's perspective, UTM system might be integrated with applications that would support drone operators in requesting authorisations via the submission of standardised drone flight plans (dFPL). Properly prepared and submitted dFPL will be verified according to Specific Operations Risk Assessment (SORA) analysis requirements and would result in legal flight permit. As UTM would act as a single point of contact (SPoC), it would enable the fast and smooth authorisation of flights through different airspace zones managed by different airspace authorities. Additionally UTM systems might provide some communication services between drone operators and authorities. Such communications could be conducted via a dedicated protocol, like Controller-Drone Data Link Communication network. This would allow UTM to communicate with the drone pilot in any emergency situations and would allow e.g. to order him to leave the zone or to land.

To grasp the sense of urgency surrounding the establishment of a comprehensive UTM, it is essential to understand the U-space rollout (illustrated in Figure 21). U-space is a set of new services and specific

procedures designed to support safe, efficient and secure access to airspace for large numbers of drones [64]. The progressive deployment of U-space is linked to the increasing availability of blocks of services and enabling technologies. Over time, U-space services will evolve as the level of automation of the drone increases, and advanced forms of interaction with the environment are enabled (including manned and unmanned aircraft) mainly through digital information and data exchange [64].

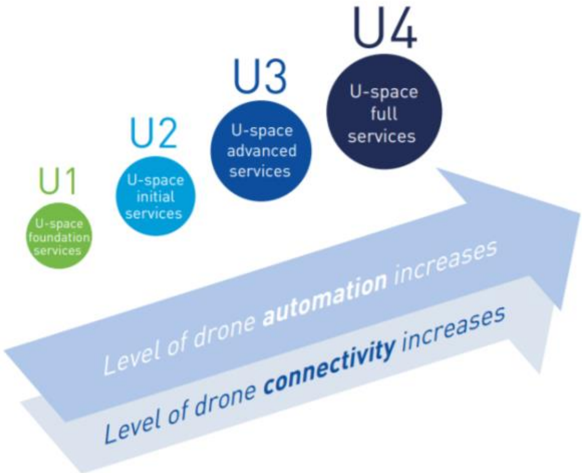


Figure 21 U-Space roll out [64]

Main goal of the UTM is to integrate all airspace related data, restrictions, services and components to provide fair, safe and secure access to it for all stakeholders involved in business value chain of U-space (users and service providers). Mentioned value chain involves entities such as: "legacy" ATM entities (airports and airfields, military, etc.) as well as U-space service providers like municipalities and supplemental service providers (e.g. 5G telecommunication network operators, logistic service providers or drone's support infrastructure providers, etc.) and UAS operators. Such approach is promoted by EASA.

2.4.2 Public Safety

Natural and human-instigated disasters destroy environments and put public safety at risk. These situations include natural disasters such as earthquakes, wildfires, storms, landslides, tsunami, CBRNE (chemical, biological, radiological, nuclear or explosive) related events and even terrorist attacks. In these situations, it is difficult and unsafe for relief workers to access areas and to provide assistance. Furthermore, natural disasters can create physical disturbances that have the power to cause significant damage to cities and vulnerable communications equipment that is responsible for supporting these areas. Disruptions caused by physical damage to the communications equipment are likely to be incredibly expensive and time-consuming to restore, hindering the process of providing emergency response to those affected by the disaster. At the same time, communication networks tend to become congested with high levels of data traffic during disasters as those impacted seek to contact family and friends, and hundreds more upload pictures and videos of the damage, resulting in deterioration of network service, blocking of new connections, and loss in data transmission.

In Sendai City (Japan) and Nokia successfully conducted a test flight of a Nokia drone on a private LTE network provided by Nokia Digital Automation Cloud. They tested the potential use of drones during a tsunami or other disasters to help in prevention and mitigation efforts. The test verified that using a private LTE network to control and communicate with the drones is an effective means for enhancing situational awareness and communicating with the affected population during a disaster. Nokia deployed a private LTE network near the Minami-Gamo Water Treatment Centre using its plug-and-play digital automation cloud technology. Using speakers, HD cameras and thermal cameras mounted on Nokia drones, the testers delivered recorded and real-time voice messages and conducted aerial

monitoring using HD and thermal camera video streaming from the drones. During the simulated disaster, the testers were able to issue a major tsunami warning to evacuees in coastal areas through the drone speaker and monitor the tsunami arrival zone and coastal areas through drone camera images. They also guided people to evacuation sites using the drone to convey directions and monitored the movements of evacuees using the drone camera. The test also highlighted how first responders can facilitate disaster prevention and mitigation without risk to the personnel managing the evacuation activities.[148], [149].

UAVs equipped with thermal cameras can be used to quickly locate victims of natural disasters regardless of the time of the day (especially during night-time operations). A swarm of UAVs can cover more ground quickly and efficiently. In addition, HD live stream can be transmitted to a larger monitor for easier spotting of subjects in real-time. This allows pilots or command crews to guide rescue teams to the precise location of their subjects, and the aerial view aids in steering those crews around any obstacles or hazards that may be in their path. Once a subject has been spotted (or possibly spotted), zoom cameras can be used to check on their well-being to analyse the severity of the rescue and make sure rescue teams have the equipment necessary to get their subject back safely.

2.4.3 Situational Awareness

The common ground in the situational awareness scenarios that 5G!Drones will trial is their relevance with the Internet of Things (IoT), one of the technologies behind the 21st century disruptive innovations, such as smart city and smart agriculture. The Internet of Things (IoT) refers to networked physical assets like sensors, drones, vehicles, and cameras [68]. Equipping drones with IoT devices allows the offering of new types of services that can be delivered only from the sky. Depending on the target objectives, different IoT devices could be considered on-board the drones. This includes HD camera, LIDAR, gas sensor, humidity/temperature sensor, etc. Moreover, while UAVs could be deployed for a specific mission (e.g., mail delivery), the on-board IoT devices would allow providing added value services, simultaneously to the drones' original tasks. This creates a novel ecosystem that supports IoT in the sky.

In a similar spirit, environmental monitoring or smart agriculture scenarios involve remote inspection and potentially the deployment of a large number of sensors. The collection of sensor readings by physical site inspection is a time-consuming task, while if sensors are equipped with networking capabilities for automatic transmission of their readings over a (wireless) network, the radio and core network segments may be put under significant strain, especially if the density of sensors is large and network capacity is scarce.

In the context of situational awareness, we can identify three main scenarios with different network requirements:

1. The first scenario focuses on infrastructure inspection, where the sensing devices are onboard and require the generation and transmission of large volumes of data, thus requiring a high-bandwidth link.
2. The second scenario involves the use of UAVs to assist in the collection and relaying of data from sensing devices with communication capabilities deployed on the ground, where the challenge is to handle the massive amounts of terminal devices.
3. The third scenario focuses on location services, where the use of global navigation systems is not applicable, such as indoors and in tunnels.

5G networks with low latency and high bandwidth will help UAV operators to carry out BVLOS operations transmitting the LIDAR and camera payload data in real time, giving quicker and more efficient results. Currently data is gathered on the drone and analysed after the flight. Transmitting video and LIDAR data live using 5G could cut processing time in general and therefore save resources. In the example of checking power lines for faults, real time data analysing could determine a faulty

insulator while flying. Then the operator could pause the flight and do additional check on the faulty part and then continue the flight. Control of the UAV can be more intuitive and safer when the latency is low.

Situation awareness use cases can be coupled with additional technologies that are combined with 5G such as IoT and edge computing (as shown in Figure 22 UAVs Situation awareness technologies [68]

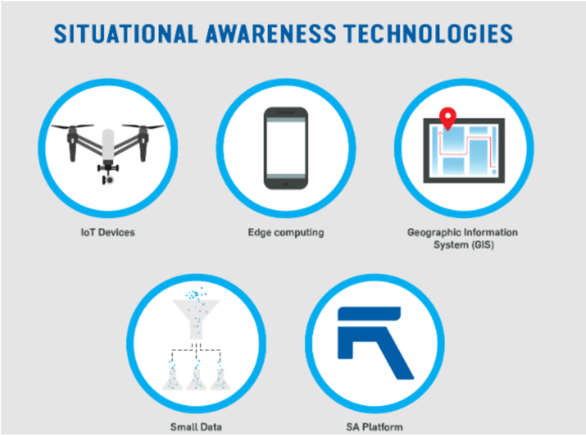


Figure 22 UAVs Situation awareness technologies [68]

2.4.4 Connectivity during Crowded Events

Overall, a major advantage of employing drones in massive events is that they can dynamically and timely improve the capacity and coverage of cellular networks. To address this challenge, efficient network planning tools targeting spontaneous and rapidly changing scenarios for dynamic network design need to be developed. Based on this advantage, one of the emerging applications of drones currently being studied within the 3GPP community is their use as a platform for small cells in wireless networks. The key benefit of drone-based small cells is to timely and dynamically provide or improve the network capacity by moving them to the location with the temporarily increased traffic demands.

Drone-mounted flying base stations (DBSs) can be used to provide replacement coverage in crisis or augment coverage and capacity in high demand areas. In fact, given the rising site rental costs for the growing number of small cell deployments, DBSs can be an attractive alternative to conventional roof or pole mounted base stations. Although the concept of DBS is still in its infancy, the research interest in this future technology is growing rapidly. Many academic researchers are now actively working in the area while industry players are also beginning to join the game [181].

Already in 2016, a solution was successfully tested in Scotland, where the drone carried a Nokia 4G cell, which ensured connectivity in hard-to-reach areas [69]. At the IEEE 5G Summit in Istanbul in 2019, Turkcell presented their Dronecell - Turkcell's Flying Base Station solution and vision on how drones and mobile technology can work together for mutual benefits and what challenges need to be solved [37].

During crowded events, such as football games, public demonstrations, and political protests, cellular networks face an extremely high demand for communication capacity during the event. This results in deteriorated network service with dropped calls and degraded Internet connectivity. Although telecommunication companies have deployed temporary solutions, such as portable base stations called Cells on Wheels (COWs) for increasing communication capacity and free Wi-Fi access points for offloading Internet traffic from cellular base stations, crowded events remain a major challenge for cellular network operators.

In 5G!Drones, using an on-demand swarm of UAVs equipped with 5G small cells can solve this challenge by providing better coverage resulting in fewer dropped calls and better Internet connectivity

to people attending the events. Since in this use case drones are flying over a crowded area, reliable control of drones (i.e., flying capabilities and residual battery life) is needed.

3 REGULATORY ECOSYSTEM IN THE 5G!DRONES CONTEXT

As the 5G!Drones project plans UAV flights for 2020-2022, it is important to analyse the current (2020) regulation as well as the under formulation future (2021-2022) regulatory impact. The regulatory analysis focuses on the points that affect the 5G!Drones project. In the case of drones, this means analysing the regulation of the use of drones weighing up to 25 kg.

The regulation affects UAV flights in four parts:

- Requirements of UAVs and operators
- Spectrum regulation on payload and trackers on board
- Requirements of flight routes and locations and U-space regulation
- Requirements arising from the GDPR for the handling of information collected by the drone.

The first part, i.e. UAV flights and operators determine the general requirements for UAV models and operators and pilots to perform flights.

The second part deals with the communication between the drone and the ground points. This part is regulated by the authorities in the field of radio communications. Depending on the task, different communication devices would be used on board UAVs, which are mainly:

- Send Control & Commands (C2 info) to the drone and receive telemetry information and video stream from the drone's built-in camcorder from the drone using the Remote Controller.
- Additional cameras and sensors that collect a variety of information that is sent immediately to the ground or stored on board a drone.
- 4G/5G smartphones or other communication devices to send camera/sensor information to the ground.

The third part deals with the possibility of a drone flight at a specific location and time, i.e. how a specific drone flight is placed in a complete U-space.

The fourth part deals with the privacy and data protection related requirements e.g. when and what the drone can record with the camcorder and how to handle the information collected by the drone.

This chapter is divided into two subchapters, dealing with topics respectively:

- Section 3.1 Current national regulations for UAV flights and operators and spectrums, and
- Section 3.2 European Union regulatory impact 2020-2022.

3.1 Current National Regulation for UAV flights, Operators and Radio Equipment

Since 2015 most of the European countries have established UAV related regulation or have amended a pre-existing regulation. On July 1st, 2020 the European Union UAV regulation will take effect and all EU member states are now in the process of aligning. Regulation (EU) 2019/947 and Regulation(EU) 2020/639 [1], which sets the European rules applicable to the use of aircraft without crew on board enter into force on July 1, 2020. The national rules will therefore remain gradually in force until December 2, 2022 and a transitional arrangement is considered after this date [70].

In the 5G!Drones Project, drone flights will take place in France, Finland and Greece. Evidently, the regulations of these three countries have been scrutinized and keynotes are presented below.

3.1.1 French Regulation

French CAA (DGAC - Direction Générale de l’Aviation Civile) deals with all the components of civil aviation incl. UAV related fields, manages the preparation of regulations related to UAVs and provides

guidance within its competence. The French CAA also publishes on its website the latest information on the regulation and organization of UAVs [70].

UAV flights are regulated in France by the following legislation:

- Amended decree of December 17, 2015 relating to the use of airspace by civil aircraft which circulate without anyone on board - Law No. 2016-1428 of October 24, 2016 relating to strengthening the safety of the use of civil drones [71].
- Order of May 18, 2018 relating to the requirements applicable to remote pilots who use civil aircraft operating without a person on board for purposes other than leisure [72].
- Decree n ° 2018-882 of 11 October 2018 relating to the registration of civil aircraft operating without anyone on board [73].
- DGAC Order of October 19, 2018 relating to the registration of civil aircraft operating without anyone on board [74].
- Decree n° 2019-348 of 19 April 2019 relating to the information notice relating to the use of aircraft operating without anyone on board
- In application of article D. 133-10 of the Civil Aviation Code, aerial photography requires a prior declaration (in the case of drones, it is possible to be satisfied with an annual declaration, valid for the whole of France) [70].
- Aircraft without people on board (drones and models) weighing more than 800 grams must issue an electronic alert from June 29, 2020. However, aircraft which will be registered before June 29, 2020 will have an additional period six months (December 29, 2020) to comply. Decree n ° 2019-1114 of October 30, 2019 taken for the application of article L. 34-9-2 of the Post and Electronic Communications Code [75] as well as the decree of December 27, 2019 defining the technical characteristics of electronic and luminous signalling devices for aircraft operating without persons on board [76].

3.1.1.1 General Requirements

A. Requirements for the UAV Operator

In order to fly a UAV in France, the operator is required to be registered to the DGAC as a UAV operator and must have written a “Specific Activities Manual” (translated from French “Manuel d’Activités Particulières” or MAP). The MAP includes the following information: the drones owned by the company, the name of its pilots and their licenses and how the pilots are trained by the company.

B. Requirements for Foreign Drone Operator

In the case of a foreign operator already detaining the required authorisation in his country, these authorisations can serve as a basis for asking an authorisation to fly in France (especially for EU members) and therefore liberating the operator from some or all the requirements previously described (e.g. MAP, Design Certificate, and License).

C. Requirements for the Pilot

Every pilot professionally operating a UAV in France must possess a UAV license. Depending on the mass of the UAV and the conditions of the flight, the pilot can be required to have an “Ability Certificate” (translated from French “Certificat de compétences”) which is delivered by the DGAC after validating the pilot’s ability to fly a drone.

In some specific cases, a manned aircraft license can be required (for BVLOS flights over very long distances).

D. Requirements for the UAVs.

Every drone over 800 g must be registered to the DGAC and is assigned a unique ID. This ID must be clearly written on the UAV along with the name, address and phone number of the owner. For some scenarios, a “Design Certificate” can be required. It must be validated by the DGAC and it certifies that the UAV is equipped with the necessary software and hardware components (e.g. parachute, buzzer, geofencing etc.) allowing it to fly safely in given conditions.

1. UAV on-board tracker

UAV weighing more than 800 grams must issue an electronic alert from June 29, 2020.

2. Standard scenarios

The French regulation establishes four standard scenarios (S1-S4 described in Table 2) based on how the UAV is piloted (VLOS or BVLOS), its’ MTOW and the area (populated or unpopulated – aeronautical definition for urban areas, and gathering of people otherwise). Each scenario has its own restrictions for altitude, distance to pilot and its own requirements for the pilot and company operating the drone.

Table 2 France standard scenarios for UAV flights

Scenario	UAV MTOW ≤ 2 kg	UAV MTOW 2 kg < M ≤ 8 kg	UAV MTOW 8 kg < M ≤ 25 kg
Scenario S1: **VLOS and unpopulated area**	Distance to pilot < 200 m Required: UAV pilot licence Design Certificate (required): No Max height: 150 m		
Scenario S2: **BVLOS and unpopulated area**	Distance to pilot < 1000 m Required: UAV pilot licence Design Certificate (required): Yes		
Max height (m)	150	50	50
Scenario S3: VLOS and populated area	Distance to pilot < 100 m An authorisation must be asked to the municipality within a 5-day notice. Required: UAV pilot licence Max height: 150 m **Special requirement for S3:** Drones over 2 kg are required to be equipped with a parachute or any device capable of limiting the ground impact energy to a maximum of 69 J in case of a crash. Triggering the device must also activate a buzzer and stop the engines from rotating. For drones over 4 kg, this device must be powered by its own battery and triggered by a separate link than the main control link.		
Design Certificate (required)	No	Required	Specific authorization from DGAC
Scenario S4: **BVLOS and populated area**	Distance to pilot = infinite Max height: 150 m Design certificate: Required and must have been attributed to the drone by the DGAC		
Required pilot licence	Theoretical Ability Certificate+ Hours of flight+ Specific Activity Manual	Specific authorization from DGAC	Specific authorization from DGAC

In France there are several restricted areas (illustrated in Figure 23) for drone flights, which can be accessed using the online Geoportail map [77] or DGAC i.e. French CAA website for UAV Activities [78]. These areas are forbidden or limited for recreational uses, but can be access for professional uses

with the specific authorisations. Populated and unpopulated areas use the aeronautical definition. If the location is in agglomeration, then it is a populated area.

The 5G!Drones project will include VLOS drone flights in France, in Sophia Antipolis, near to Eurecom premises with 2 locations with maximum height is 30 m AGL:

- Terrace (which is populated area and Scenario S3 is relevant) and
- Parking slot (which is populated area and Scenario S3 is relevant) .

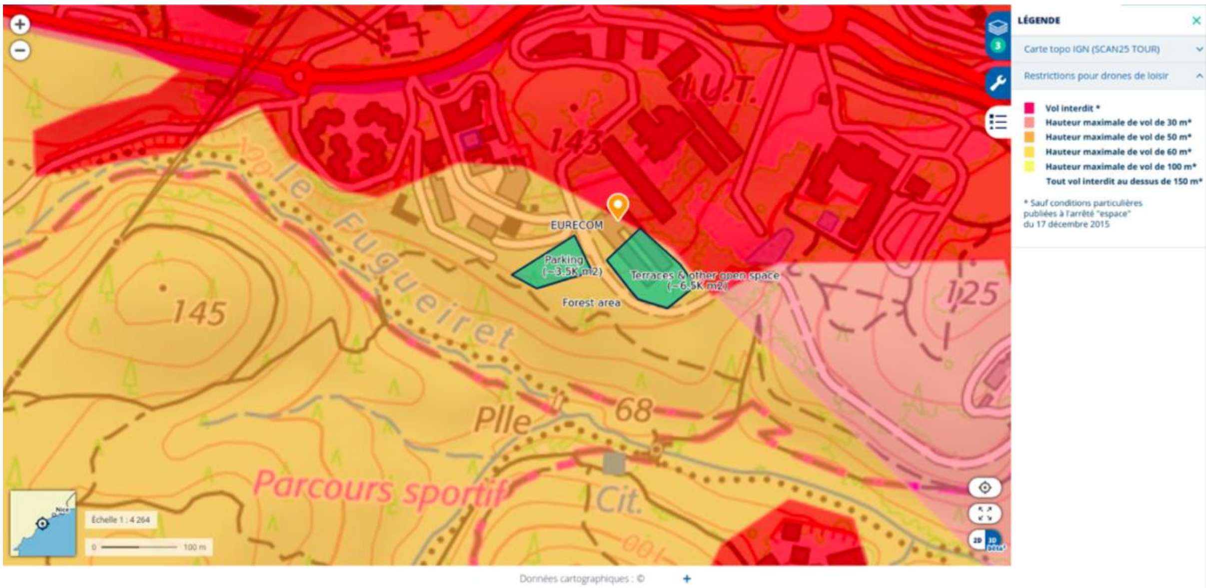


Figure 23 Flight restrictions and flying areas in EURECOM's 5GEVE premise

French regulations (described in Table 3) must be taken into account for the trial of 5G!Drones project in the Eurecom 5G testbed.

Table 3 France CAA standard scenarios for 5G!Drones trials in France

Use case/scenario	Operator	UAV model	Added Safety	MTOW kg	FRA Standard scenario
UC1:SC1 UAV Traffic management	CAF	DJI Mavic	-	1,1	S3
	NOK	Nokia drone	Parachute	11	S1
UC2:SC1 Monitoring a wildfire	CAF	DJI Mavic	-	1,1	S3
UC2:SC2 Disaster recovery	HEP	Hepta-19	Parachute	15	S1

3.1.1.2 France Spectrum Regulation

In the 5G!Drones project trials in France is planned to use series-produced drones DJI Mavic as well as individual models from separate manufacturers Nokia, Hepta. The remote controllers of these drones meet the French radio communication requirements (shown in Table 4).

Table 4 Frequency bands commonly used on UAVs in France [79]

Band	Maximum Transmission Power
433.05-434.79 MHz	1 mW (or 10 mW with a 10% use rate)
863.0-869.2 MHz	25 mW
869.3-869.4 MHz	10 mW
869.40-869.65 MHz	500 mW
869.7-870.0 MHz	25 mW
2.400-2.483 GHz	100 mW
5.725-5.875 GHz	25 mW

Using 5G devices on-board a drone requires permission from the France Radio Communication Agency (shown in Table 5).

Table 5 Drones and radio communication devices in 5G!Drones trials in France

Drone	Telemetry	Radio command	Drone video	Devices attached to the drone
DJI Mavic	2.4 GHz for C2		5.8 GHz for video	5G smartphone+ LTE CatM1/M2 IoT device
DJI Matrice 210	2.4 GHz for C2		5.8 GHz for video	5G smartphone+ LTE CatM1/M2 IoT device
Nokia	5G modem	868 MHz	5G modem	5G modem
Hepta-19	2.4 GHz	2.4 GHz	5G modem	5G modem

3.1.2 Finland Regulation

The Finnish Transport and Communications Agency Traficom (also named CAA) is an authority what deals all UAV related permits, licences, registration, approval, safety and security matters. On 29.01.2020 there was in Traficom registry 2962 professional drone operators and 3815 drones.

UAV flights are regulated in Finland by the following legislation:

Current drone regulation is based mainly on:

- the Finnish Aviation Act 864/2014;
- the Use of remotely piloted aircraft and model aircraft – regulation OPS M1-32;
- EU/923/2012 on the Common rules of the air (SERA) and
- Government Decree 930/2014 on where aviation is restricted.[80], [81].

3.1.2.1 General Requirements

Current regulation separates professional and hobby use. The only requirements for professional operators are:

a) To register the operator details on the CAA homepage
b) Contact information with operator´s name easily visible on drone
c) Flight logbook maintained for at least 2 years

d) 3rd party liability insurance complying with (EC) No 785/2004 minimum 1 000 000 EUR

No competence requirements exist.

General restrictions regarding airports, airfields and helipads and privacy:

- Flying closer than 1 km from an airport runway is not allowed without permission from the air traffic control tower.
- Flying at distances between 1 km and 3 km from an airport runway is allowed up to the height of surrounding obstacles. In close vicinity to an obstacle, the operator may fly 15 m over the obstacle height with permission from the obstacle owner.
- Flying in the control zone of an airport but still further away than 3 km from the airport runways, the maximum allowed flight altitude is 50 m.
- The flight must not endanger or disturb the operations of an emergency services helicopter.
- When flying close to airfields, the operator needs the airfield operator's permit to fly closer than 1 km, or if the airfield has published local regulations for flying a drone the operator must follow them.
- For flying closer than 600 m to helipads, the operator needs to have the helipad operator's permission. You can find helipad information in AIP Finland, section AD3.
- Flights must not cause danger to or disturb other people.

Scenario-specific restrictions are shown in Table 6.

Table 6 Finland regulation for VLOS, EVLOS, BVLOS scenarios

Scenario	MTOW Sparsely (unpopulated) area	MTOW Densely populated area	Maximum altitude
VLOS	<25 kg MTOW Allowed No preapproval	<3 kg: • Familiar with area before flying • Ensure airworthiness of drone • Assessment that flight can be safely conducted 3-7 kg: • Description of Operation • Safety assessment • Operating procedures under Normal, Abnormal and Emergency conditions • Requires sending documents to TrafiCom before operation but no approval needed/given	150 m
EVLOS	<25 kg MTOW Allowed also when spotter is out of sight and communicates using technical aids. No preapproval	Need special permit from CAA.	150 m
BVLOS	<25 kg MTOW • Allowed in special airspace (Restricted or Danger area), with: • Description of Operation • Safety assessment • Operating procedures under Normal, Abnormal and Emergency conditions • Requires sending documents to TrafiCom before operation. • No approval is needed nor given.		150 m

Requirements for an exemption from maximum mass, altitude limit or other is subject to approval from the CAA. To create a written application for exemption to TrafiCom (CAA), with attachments:

- Description of the operation,
- Safety assessment and
- Procedures for normal operations and emergencies.

Description of Operation written document includes:

- The operations, including information on the operating area and operating time as well as the flight altitudes and aircraft used.

Safety assessment written document includes hazard identification, risk assessment and risk mitigation measures.

- Procedures for normal operations and emergencies.

Procedures for normal operations and emergencies written document includes:

- Operational instructions that include a description of procedures both for normal operations and emergency/malfunction procedures. For example: in an emergency pilot must be able to land a drone so that risk for people and property is minimal. This requirement can be fulfilled using an operational procedure, a safety equipment or combination of both.

Description of the operation, Safety assessment and Procedures for normal operations and emergencies shall be sent to Finnish Transport Safety Agency (CAA) before the flights. Documents should be sent to **kirjaamo@traficom.fi** with the email titled “RPAS risk assessment notification”. Operator must keep records of operational instructions and safety assessments for at least 3 months. Finnish CAA uses SORA-based (Specific Operation Risk Assessment) methodology for risk assessment.

BVLOS operations shall be performed in areas that are specifically reserved for that purpose (Danger or Restricted areas). For BVLOS operations a *‘Danger Area’ (Tempo-D)* will be reserved and activated a day before the proposed trial. A drone operating in a Danger area is not required to give way to other aircraft.

Application for Danger or Restricted areas follow an 8-week process and comes with a currently fixed fee of 320 euro. Danger areas can be applied for and allowed almost anywhere, unless objected by other airspace users. Examples exist of civil drone D-areas established in Finland up to 120 m or 1200 m during 2019. For BVLOS flights that take place automatically, the pilot does not have to be in the area, unless this is a separate condition for Traficom's authorization.

Night operations follow the same rules: if the drone has sufficient lighting and the surrounding airspace can be monitored, VLOS rules are applied. Only if the drone cannot be observed, must BVLOS rules be applied.

No legislation yet exists for eVTOL’s or Air Taxi UAV-s carrying people or heavier than 150 kg, for such operations applicable rules for manned aviation are applied.

Indoor flights are not covered by the Finnish Aviation Act. Therefore, general safety requirements must be followed. For example, UK CAA has explained in Air Navigation Order 2016 (ANO 2016): Indoor use - Flights inside buildings have nothing to do with air navigation because they can have no effect on flights by aircraft in the open air. As a result, flights within buildings, or within areas where there is no possibility for the unmanned aircraft to ‘escape’ into the open air (such as a ‘closed’ netted structure) are not subject to air navigation legislation. Persons intending to operate unmanned aircraft indoors should refer to the appropriate Health and Safety At Work regulations [82].

When **flying over people** the maximum take-off mass of the aircraft must not exceed 7 kilograms (any rescue device attached to the aircraft is not counted in the take-off mass). The aircraft must be flown at

an altitude that, in the case of an emergency, allows the aircraft to be landed in a manner that minimises risks to third persons or their property, or the aircraft must be so equipped or have such characteristics that the risk to third persons and their property is minimal.

Traficom's (CAA) UAV website Droneinfo.fi have links to all relevant legislation, as well as Droneinfo App for mobile phones where static no-fly zones and restricted areas can be found. As of May 04, 2020 **www.aviamaps.com/map** is an official source of Navigation Warnings and Airspace Usage Plan/Update Usage plan (AUP/UUP) information, including temporary Danger and Restricted areas (illustrated in Figure 24 and in Figure 25). The Finnish Police and many professional drone operators also use the Aviamaps service to make voluntary flight notification submissions available to all aviators [83].

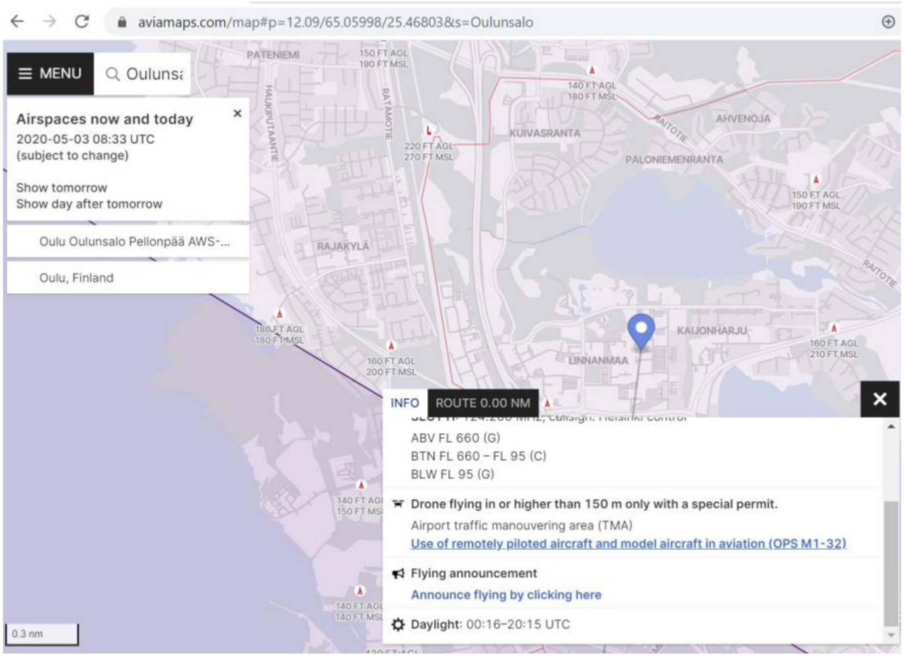


Figure 24 Aviamaps.com screenshots about Oulu 5GTN testbed

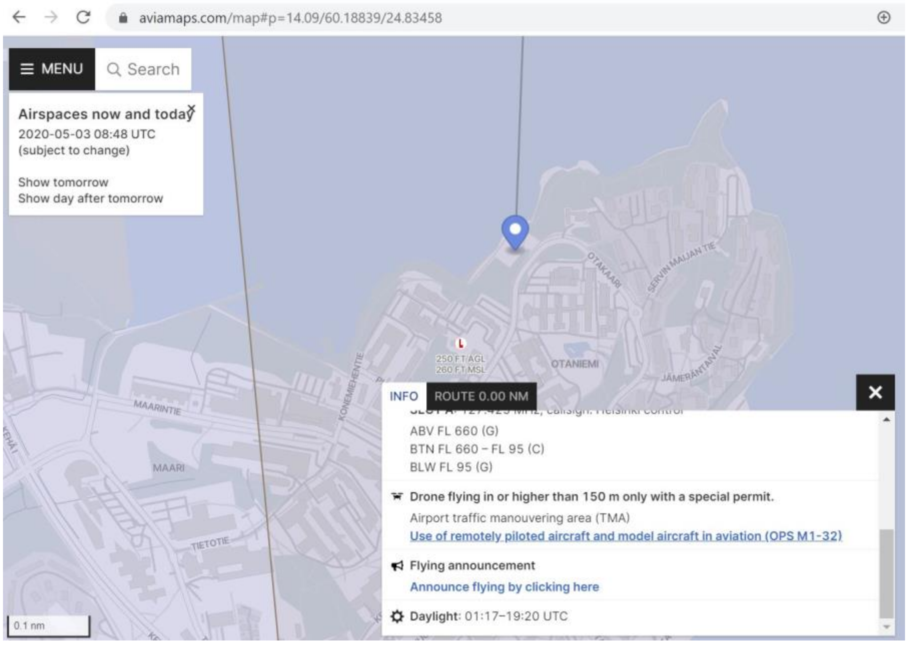


Figure 25 Aviamapsc.om screenshot about Aalto X-network testbed

Finnish regulations (described in Table 7) must be taken into account for the trial of 5G!Drones project on the Aalto University (Espoo) and in Oulu University (Oulu) testbed:

Table 7 Finland UAV flights regulation for 5G!Drones trials in Finland

Use case – scenario	Operator	UAV model	Added Safety	MTOW kg	FIN regulation scenario
UC1:SC2 3D Mapping	OU	DJI Matrice	Safety net	6	Indoor flight
UC1:SC3 Logistics	CAF	DJI Mavic	-	1.1	VLOS <3 kg in densely populated area
	CAF	DJI Matrice 210	-	6	VLOS 3-7 kg in densely populated area
UC2:SC3 Police	CAF	DJI Mavic	-	1,1	VLOS <3 kg in densely populated area
	CAF	DJI Matrice 210	-	6	VLOS 3-7 kg in densely populated area
UC3:SC1:SSC2 Inspection	HEP	Hepta-19	Parachute	24,9	VLOS <25 kg in densely populated area
UC3:SC1:SSC3	ALE	Hydradrone	Parachute	8 kg	VLOS <25 kg in densely populated area
UC3:SC2 Onboard IoT	AU	Aalto drone	-	2,9	VLOS <3 kg in densely populated area
UC3:SC3 UAV in non-GPS condition	NOK	Nokia drone	-	11	VLOS <25 kg in densely populated area

3.1.2.2 Finland Spectrum Regulation

The Finnish Transport and Communications Agency Traficom (also previously mentioned Finnish CAA) leads and governs the commercial radio frequencies.

Traficom manage special website for Drones and remotely piloted aircraft (UAS/RPAS) - frequencies and radio licences [84].

UAVs, depending on their use type (professional or non-professional one), can use either licensed frequencies or frequencies exempt from radio license requirements. Non-professional UAS use is considered to make use of frequency opportunities under general authorizations (i.e. without any individual rights). The most common use is found in the 2400-2483.5 MHz (ERC/REC 70-03, Annexes 1 and 3) and 5725-5875 MHz bands (non-specific use according to ERC/REC 70-03 Annex 1) under the current regulatory conditions set out in ERC/REC 70-03.

Other usage opportunities exist in the 433 MHz and 863-870 MHz ranges. These usage opportunities are based on harmonized frequency use without restrictions (RE Directive Class 1 equipment) and use is only bound to the technical and operational conditions provided in the ERC/REC 70-03 and the EC Decision for SRD (2006/771/EC as amended) [85].

There are limitations to use frequencies above 2.4 GHz "The use of non-specific short-range devices are also allowed on board airborne aircraft or in any other equipment used in aviation. Voice applications and other short range audio applications and video applications are allowed only on frequencies above 2.4 GHz, unless stated otherwise" [86].

Currently it's not allowed to use modems and mobile phones on board an UAV [139, 86]. A permission to use UAV with attached mobile phone or modem can be applied via Traficom web service [87].

In the 5G Drones project trials in Finland is planned to use 5G mobile-phones and modems on-board drones (shown in Table 8). Therefore, the relevant permits must be sought from Traficom. IN trials will be used series-produced drones DJI Mavic, DJI Matrice as well as individual models from separate manufacturers Nokia, Hepta and Alerion. The remote controllers of these drones meet the Finland radio communication requirements.

Table 8 Drones and radio communication devices in 5G!Drones trials in Finland

Drone or ground device	Telemetry	Radio command	Drone video	Devices attached to the drone
DJI Mavic	2.4 GHz for C2		5.8 GHz for video	5G smartphone
DJI Matrice	2.4 GHz for C2		5.8 GHz for video	5G smartphone
Nokia	5G modem	868 MHz	5G modem	5G modem
Hepta-19	2.4 GHz	2.4 GHz	5G modem	5G modem
Alerion Hydradrone	868 MHz	2.4 GHz	5.8 GHz/5G modem	5G modem
NB IoT sensor		800 MHz	No	No

3.1.3 Greece Regulation

Hellenic Civil Aviation Authority (HCAA) is responsible for authorizing Unmanned Aircraft Systems[2] (UAS) flights in ATHINAI FIR / HELLAS UIR [88]. It employs the UAS – Flight Regulation Support System (UAS-FRSS) system, that as shown in Figure 26 consists of the **DAGR** (Drone Aware GR) and HCAA's Special Registry (**ΥΕΔ**) sub-systems.

HCAA aims to help UAS owners to abide by regulations for operating drones/unmanned-aircraft systems (UAS)/Remotely Piloted Aircraft Systems (RPAS), ensuring thus the flights' safety of airplanes & helicopters in ATHINAI FIR / HELLAS UIR. Nevertheless, the citizens' protection from accidents and any type of property damage, and the non-allowance of possible UAS flights over restricted areas, such as areas above military and industrial sites, public buildings and areas of public interest, are defined/delineated by the Ministry of National Defence or the Civil Protection Ministry or other Ministries.

[2] Unmanned Aircraft System (UAS) is the unmanned aircraft (UA) along with all the associated equipment pertaining to its support (control station, data connectivity and remote control, navigation equipment, etc.) which is necessary for the operation of an unmanned aircraft. The UAS is either free (free UAS) or can be attached (tethered UAS) in fixed or mobile bases. [89]

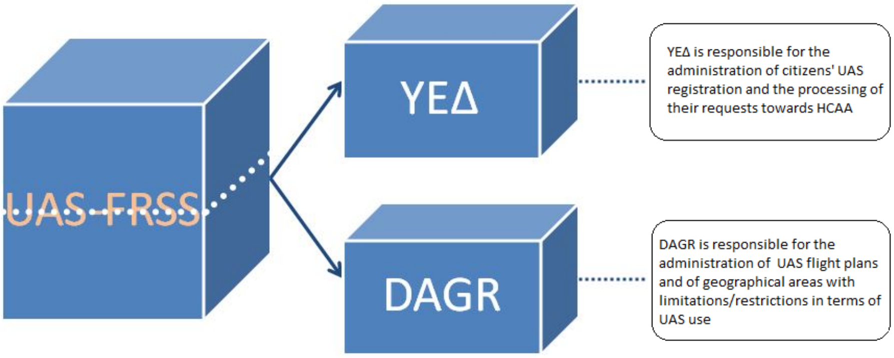


Figure 26 Unmanned Aircraft Systems – Flight Regulation Support System (UAS-FRSS) in Greece

UAV flights are regulated in Greece by the following legislation that has come into force since 01.01.2017

- Regulation – General framework for flights of Unmanned Aircraft Systems - UAS (Published in Government Gazette B/3152/30.9.2016 - Original text published in Greek Language).

3.1.3.1 General Requirements

A. Requirements for UAS Operator (owner, and / or lessee of one or more UAS)

The Owner / operator of a UAS whose flights are conducted at a distance more than 50 m. from the operator, is obliged to declare in writing the details of UAS, the identity of the Owner/ Operator with identification validation in a Citizen Service Centres or other competent service, by completing the online form which can be found at the HCAA website (**www.ypa.gr**) and to send them by electronic means (email / FAX) to HCAA.

B. Requirements for UAS registered abroad

For UAS registered abroad, which carry out flights over a distance more than 50 m from the remote pilot, it is required to be submitted by electronic means, the proof and registration code in the respective foreign registry. Regarding the required certificates of a UAS, operator and pilot, if the existing foreign certificates are recognized by the Greek and European Law, they are accepted. Otherwise, those interested will apply for their registration in Greek records or Registry.

C. Requirements for Remote Pilot

Remote Pilots of UAS: i) of A2 "Open" Class and all subcategories of "Open Class" in case of-professional operations, ii) of "Specific" Category, and iii) of "Certified" Category shall hold a certificate (licence) granted by HCAA / Flight Standards Division. According to regulation published in Government Gazette ΦΕΚ Β-4527/ 30.12.2016 (90), there are different licence categories (UAS Pilot A –> UAS Pilot E), depending on the MTOM of the UAS.

D. Requirements for UAVs

The UAS are used for commercial, scientific or recreational purposes and for aerial works flights. The operator (owner or lessee) of the aircraft is obliged to declare to the Aviation Authority the type of use.

UAS are classified in the following three categories: i) "Open" category (UAS Open Category), ii) "Specific" category (UAS Specific Category), and iii) "Certified" category (UAS Certified Category), based on the following criteria:

- maximum take-off mass (MTOM),
- type of use,
- height above the surface of earth or sea where allowed to fly;

- areas (exclusive or not) to fly in;
- technical capabilities of each UAS;
- complexity of the environment of the flying operations of UAS.

Specifically, UAS Open Category is divided into three sub-categories indicated at Table 9. In general, flights of UAS Open category are performed only with unmanned aircraft of a maximum take-off mass (MTOM) less than 25 kg and are not permitted overhead groups/crowds, while the UAS remote pilot must maintain direct visual contact with the Unmanned Aircraft and the flight has to be carried out at less than 500 meters from UAS remote pilot.

In addition, UAS Specific Category is defined as a category for UAS operation likely to pose significant risks on persons, over whom the operation is conducted, while UAS Certified Category refers to UAS Category, in which the operation is conducted with requirements similar to those applicable to manned aircraft, i.e. by previously obtaining permits and airworthiness certificates. For flight operations of UAS belonging to the UAS Certified Category, the registration of this aircraft in the Registry of HCAA / Air Transport and International Agreements Division and the issuance of a special certificate of airworthiness for UAS - Special Certificate of Airworthiness (CofA) is required.

Table 9 Greek regulation Art. 7 "Open" Category Subcategories

Category (CAT)	MTOM	Requirements
A0	<1 kg	VLOS flight; Depending on the level of equipment, operators of UAS of A0 "Open" category will limit their flight to 50 m above the ground, local flight, or alternatively, having the technical capabilities to automatically define their flight height and route, to the limit of 120 m from the Ground Level (AGL) or Mean Sea Level (MSL)
A1	1-3.99 kg	VLOS flight; the UAS technical features should ensure that they fly below 120 m from the ground or sea surface in remotely controlled local flight operation and will have the means to automatically limit the airspace in which they can enter. CAT A1 UAS must have activated geo-fencing capability.
A2	4-25 kg	VLOS flight; CAT A2 UAS should have active the capacity of identification and updated geo-fencing.

According to the visual contact kept by the remote pilot of the aircraft, UAS flights are classified as follows:

- Flight with visual contact (**Visual Line Of Sight – VLOS**)

  UAS Flights with VLOS are permitted at a maximum distance of 500 meters horizontally and 120 m vertically from the remote pilot. Operations at a greater distance from the system operator may be permitted if a safety assessment has been submitted and approved as acceptable and in case of a flight over 120 m, a license has been granted from HCAA / Flight Standards Division.

- Flight with extended visual contact (**Extended Visual Line Of Sight – EVLOS**)

  During flights with Extended visual contact (EVLOS), UAS fly at a distance within the range of the system by the operator and 120 m from the ground or water surface, thus at a distance where the system operator is able to comply with the collision avoidance procedures. On these flights the requirement for the operator to keep direct visual contact of the operation of Unmanned Aircraft is achieved via the "visual observation" method, namely by monitoring the flight progress through its camera, by the transmission of the relevant image. The operator must submit a safety assessment plan, including risk assessment for flight operation. Suitable radio should be established in order to enable the operator to control the UAS at any time. UAS conducting flights in EVLOS conditions are recorded compulsorily in the "Specific" or "Certified" Category, undertaking the relevant obligations.

- Flight beyond visual contact (**Beyond Visual Line Of Sight - BVLOS**)

  During a UAS flight beyond visual contact, the remote pilot is not able to respond or avoid other airspace users by visual means. For a UAS intended for operation beyond system operator's visual contact, the definition of a restricted (segregated) airspace to avoid a collision is required, or to follow in full compliance, the relevant special instructions of the authorization given by the competent Air Traffic Control service Unit of HCAA. The UAS conducting flights in BVLOS conditions are required to submit a safety assessment plan, including risk assessment for the operation, as specified at the case of flights with EVLOS, and are obligatorily registered in "Specific" or "Certified" Category, taking over the relevant obligations.[89].

In order to fly legally a UAS in Greece, UAS operators should make use of UAS-FRSS. Specifically, UAS operators can be informed about the prohibited areas for UAS flights via DAGR map, which can be found at HCAA site http://www.hcaa.gr or at **http://dagr.hcaa.gr** , without having to register / login to HCAA's special registry (ΥΕΔ). However, in case a UAS flight plan has to be submitted, first the registration at ΥΕΔ must take place and then the route data for the UAS flight plan must be submitted to DAGR. The UAS that are used for flights conducted at distances greater than 50 m. from their remote pilot and all UAS used for business purposes are recorded in the Registry, while route data are submitted for each UAS flight of "Open" Category, which is conducted at more than 50 m. from the point where the remote pilot stands.

Table 10 Greece regulatory impact for 5G!Drones trials in Greece

Use case/scenario	Operator	UAV model	Added Safety	MTOW kg	Open
UC4:SC1 Connectivity extension and offloading	CAF	DJI Mavic	-	1	A1
	HEP	Hepta-19 tethered	Parachute	24,9	A2
	HEP	DJI Matrice 600	Parachute	15,5	A2

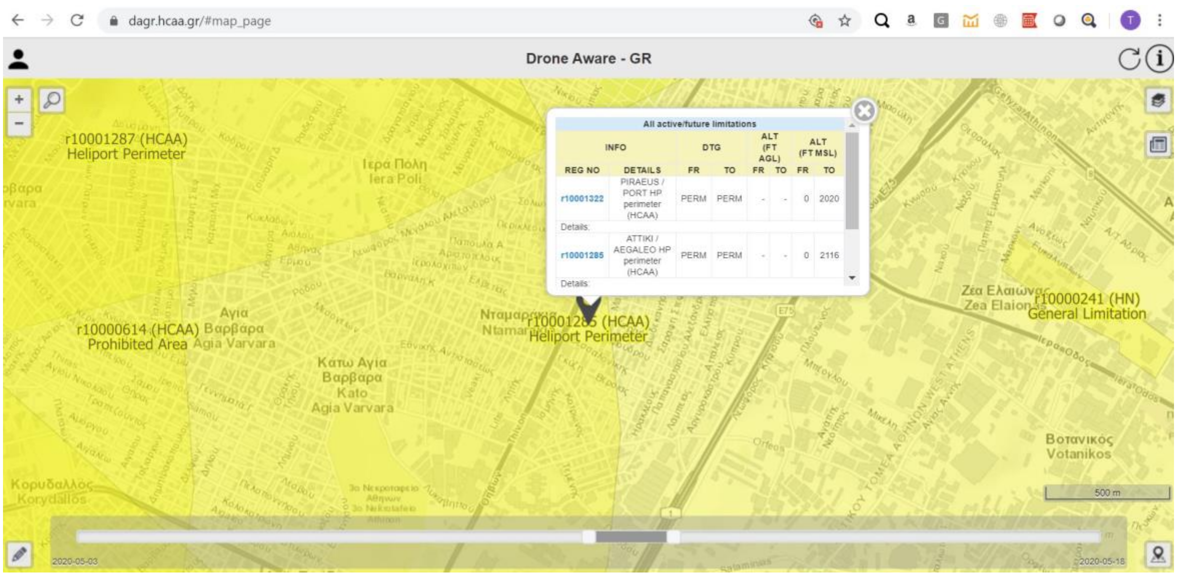


Figure 27 Flight restrictions UC4Sc1 in location Stadium Stavros Mavrothalassitis Egaleo

5G!Drones trials will take place at Stadium Stavros Mavrothalassitis in Municipality of Egaleo. Based on DAGR (Figure 27 Flight restrictions UC4Sc1 in location Stadium Stavros Mavrothalassitis Egaleo), this place is located in an area of flight restrictions, and consequently based on the Greek Regulation, a special permission from the HCAA / Air Navigation Services Regulatory Division is required.

3.1.3.2 Greece Spectrum Regulation

In terms of spectrum regulation, in Greece, the Hellenic Telecommunications & Post Commission (Greek Regulatory Authority, EETT) is responsible for managing and regulating the commercial radio frequencies, with the exception of radio and TV spectrum. There are specific frequencies identified for UAS in Greece's National Table for Frequency Allocation (NTFA). Specifically, any use of frequencies by UAS for communication between the control station (either fixed or mobile base) and UAS as indicatively for the needs of remote control, navigation, data, audio and video transmission or for passive or active identification of UAS, is elaborated according to the specified in the National Frequency Table (GG 105 / B/7/27-1-2016) and in particular Annex A.1 (Short Range Devices) of the Regulation of Terms of Use of Individual Radio frequencies or Spectrum zones of National Telecommunications and Post Commission - EETT (Government Gazette 1713 / B / 26.6.2014), as applicable. Radio equipment to be used must comply with the European decisions and instructions that have been harmonized in the Greek Legislation and are effective accordingly [90].

Using 5G devices onboard (shown in

Table 11 Drones and radio communication devices in 5G!Drones trials in Greece) a drone requires permission from the Hellenic Telecommunications & Post Commission.

Table 11 Drones and radio communication devices in 5G!Drones trials in Greece

Drone or device	Telemetry	Radio command	Drone video	Devices attached to the drone
DJI Mavic	2.4 GHz for C2		5.8 GHz for video	5G smartphone
DJI Matrice		2.4 GHz for C2	5.8 GHz for video	5G smartphone
Hepta-19 tethered drone	2.4 GHz	2.4 GHz	5G modem	5G modem
5G Base station	Uses allocated 5G frequency			

3.2 European Union Regulatory Impact 2020-2022

Regulation (EU) 2019/947, which sets the European rules applicable to the use of aircraft without crew on board, gradually enter into force from July 1, 2020.

In addition to EU regulation, the soft law of the European Union, which is strongly taken into account in practice by national CAAs, must also be taken into account. The main organisations whose opinions and recommendations influence the processing of UAVs' regulation both on national and EU level are:

- EASA (European Union Aviation Safety Agency) is an EU agency with responsibility for civil aviation safety and which among other things, provides recommendations on the regulation of UAVs and input on draft regulations to the European Commission [91].
- EUROCONTROL is a pan-European, civil-military intergovernmental organisation dedicated to supporting European aviation. EUROCONTROL's role is to ensure the safe integration of UAS while safeguarding the rights of all airspace users [92].
- JARUS (Joint Authorities for Rulemaking of Unmanned Systems) is a group of experts from the National Aviation Authorities (NAAs) and regional aviation safety organizations. Its purpose is to recommend a single set of technical, safety and operational requirements for the certification and safe integration of Unmanned Aircraft Systems (UAS) into airspace and at aerodromes. The objective of JARUS is to provide guidance material aiming to facilitate each authority to write their own requirements and to avoid duplicate efforts. At present 61 countries, as well as the European Aviation Safety Agency (EASA) and EUROCONTROL, are contributing to the development of JARUS. Since 2015, the Stakeholder Consultation Body (SCB) representing all

industry communities of interest has also been established to provide support to all JARUS activities [93].

3.2.1 European Regulatory Development Process 2015-2020

In Europe, there have been rapid developments in the regulation of UAVs activities over the last 5 years.

- **01.05.2015**: EASA published Concept of Operations for Drones. A risk-based approach to regulation of unmanned aircraft [94].
- **29.10.2015**: European Parliament adopted resolution on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (European Parliament resolution of 29 October 2015 on safe use of remotely piloted aircraft systems (RPAS), commonly known as unmanned aerial vehicles (UAVs), in the field of civil aviation (2014/2243(INI) [95].
- **26.06.2017**: JARUS published first version of the Specific Operation Risk Assessment (SORA). Second version published on 30.01.2019. The purpose of SORA is to propose a methodology for the risk assessment to support an application for authorization to operate a UAS within the specific category. Due to the operational differences and expanded level of risk, the specific category cannot automatically take credit for the safety and performance data demonstrated with the large number of UA operating in the open category. Therefore, SORA provides a consistent approach to assess the additional risks associated with the expanded and new operations not covered by the open category (1.2.a, 1.2.b) [96].
- **11.06.2019**: European Commission published common European rules on drones, Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947.
- **16.10.2019**: EASA published document of issuing Acceptable Means of Compliance and Guidance Material to Commission Implementing Regulation (EU) No 2019/947. With the publication, EASA will support UAS operators and Member States in complying with the adopted EU regulation. The document includes the description of a risk assessment methodology to evaluate the danger of an UAS operation and to identify mitigation measures to make the operation safe. The methodology for conducting a risk assessment of the operations in the specific category (as defined in EU Implementing Act 2019/947 described in subchapter 3.2.2) is called SORA (Specific Operation Risk Assessment) and offers a very structured approach to evaluate all aspects and identify mitigations and safety objectives. In addition, the first pre-defined risk assessment will assist operators when applying for an authorisation in the specific category for special UAS operations, such as the ones conducted beyond visual line of sight (BVLOS), using visual observes, over sparsely populated areas or at very low level [97].
- **11.11.2019**: EASA published the Opinion 05/2019 “Standard scenarios for UAS (Unmanned Aircraft Systems) operations in the ‘specific’ category” which is proposing an amendment to the European regulation (Implementing Act) to add two standard scenarios to facilitate some operations posing a low risk only. For those the operator will be allowed to just send a declaration to the respective authority instead of applying and waiting for authorisation [98].
- **13.03.2020**: EASA published Opinion nr 01/2020 about U-space.
- **16.04.2020**: EASA published the Notice of Proposed Amendment (NPA-2020-07) to clarify the conditions under which unmanned aircraft system (UAS) beyond visual line of sight (BVLOS) operations over a populated area or an assembly of people can be authorised in the ‘specific’ category [100].
- **13.05.2020** European Commission published Commission Implementing Regulation (EU) 2020/639 of 12 May 2020 amending Implementing Regulation (EU) 2019/947 as regards

standard scenarios for operations executed in or beyond the visual line of sight. common European rules on drones, Commission Delegated Regulation (EU) 2019/945

- **01.07.2020**: Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947 will enter into force.
- **02.12.2021**: National authorisations and declarations are fully converted to the new EU system.
- **01.01.2022**: Expected entry into force of the EU U-space regulation.

3.2.2 EC Delegating Regulation 2019/945 and EC Implementing Regulation 2019/947 and EC Implementing Regulation 2020/639

On 11 June 2019 common European rules on drones, Commission Delegated Regulation (EU) 2019/945 and Commission Implementing Regulation (EU) 2019/947, have been published to ensure drone operations across Europe are safe and secure. The rules will amongst others help to protect the safety and the privacy of EU citizens while enabling the free circulation of drones and a level playing field within the European Union. On 13 May 2020 EC adopted Commission Implementing Regulation (EU) 2020/639 - amendments to EC Regulation (EU) 2019/947.

EC Implementing Regulation 2020/639 amends EC Implementing Regulation 2019/947 with definitions, implementing provisions, annex and standard scenarios for operations executed in or beyond the visual line of sight. The objective of the amending regulation is to increase the cost-effectiveness for drone operators, manufacturers and competent authorities, and to improve the harmonisation of drone operations throughout Europe. The amendments covers two standard scenarios to facilitate some UAS operations posing a low risk in the specific category. For those, drone operators will be allowed to just send a declaration to the respective authority instead of applying and waiting for an authorisation. The standard scenarios include Urban VLOS (Visual Line of Sight) and Rural BVLOS (Beyond Visual Line of Sight) above control ground area operations. The amendments are mainly based on EASA Opinion No 05/2019 [98].

These European standard scenarios (STS) are intended to replace the national scenarios S1, S2 and S3. They are based on a declarative regime, and require the use of class CE marked drones (not yet available on the market). More precisely :

- STS-01 scenario covers operations in view at a maximum height of 120 m above an empty area of third parties in a populated environment;
- STS-02 scenario covers out-of-sight operations at a maximum distance of 2 km from the remote pilot, with the help of airspace observers, at a maximum height of 120 m, above an empty area of third in a sparsely populated environment.

An operator may declare themselves according to the European standard scenario from December 2, 2021. From this date, no new declaration can be made according to the national standard scenarios. The declarations according to the national standard scenarios which will have been made before December 2, 2021 will cease to be valid on December 2, 2023. This date will mark the definitive end of the national scenarios S1, S2 and S3 [190].

EASA is currently working on the necessary amendments of existing regulations in order to accommodate drones [101], [102].

As from 01.07.2020, national rules will be gradually replaced by a common EU regulation. The purpose of this reform is to create a truly harmonised drone market in Europe with the highest level of safety. In practice, it means that once a drone pilot has received an authorisation from its state of registry, he/she will be allowed to freely circulate in the European Union.

The EU regulatory framework will cover all type of existing and future drone operations, fostering the development of innovative applications and the creation of a European market for unmanned aircraft services.

While aiming primarily at ensuring safe operations of drones, the European regulatory framework will also facilitate the enforcement of citizen's privacy rights and contribute to address security issues and environmental concerns in the benefit of the EU citizens. It will in addition enable the deployment of an Unmanned Traffic Management System, the U-space, to support the development of drone operations in low-level airspace, beyond visual line of sight and congested areas.

The European regulatory framework will be based on a risk-based and proportionate approach. The new framework will introduce three categories of operations (open, specific and certified) according to the level of risks involved:

- **Open Category**

  Operations in the open category do not require prior authorizations or pilot license. However, they are limited to operations: in visual line of sight (VLOS), below 120 m altitude and performed with a privately built drone or a drone compliant with the technical requirements defined in the regulation. To demonstrate this compliance drones that can be operated in the open category will bear a class identification label. Additional operational restrictions apply to each class of drone, in particular with regard to the distance that must be maintained between the drone and non-involved persons.

- **Specific Category**

  When the intended operation exceeds the restrictions of the “open” category, the operator should consider operating under the "specific" category (medium risk). Only high-risk operations require compliance to classical aviation rules under the "certified" category (like operating in controlled airspace). Operations involving drones of more than 25 kg and/or operated beyond visual line of sight will typically fall under the “specific” category.

  Before starting an operation in the specific category, operators must either perform a risk assessment (using a standardized method – the SORA – that will be provided by EASA) and define mitigation measures or verify that they comply with a specific scenario defined by EASA (or the national aviation authority). On that basis they will be able to obtain an authorization from the national aviation authority (in some cases a simple declaration may be enough). The authorization or the specific scenario will define the authorized operation and the applicable mitigation measures (drone technical requirements, pilot competence, etc.).

- **Certified Category**

  The “certified” category (high risk) includes operations involving large drones in controlled airspaces. Rules applicable to the “certified” category will be the same as for manned aviation: drones must be certified for their airworthiness, pilots shall be licensed, and safety oversight will be performed by the relevant National Aviation Authorities and EASA.

  A different regulatory approach will be adopted for each category. Low-risk operations (“open” category) will not require any authorization but will be subject to strict operational limitations. For medium risk operations, operators will have to require an authorization from the national aviation authority on the basis of a standardized risk assessment or a specific scenario (specific category). Finally, in case of high-risk operations, classical aviation rules will apply (certified category).

- **July 01, 2020**: Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947 and Commission Implementing Regulation (EU) 2020/639 will enter gradually into force and set following rules.

  Registration of UAS operators & certified drones becomes mandatory. All drone operators shall register themselves before using a drone:

  1. In the ‘Open’ category, with a weight:
     - more than 250 g;

- less than 250 g when it is not a toy and it is equipped with a sensor able to capture personal data;

2. In the ‘Specific’ category (regardless of the weight of the drone).
3. All certified drones (operated in high risk operations) shall be registered as well. The registration number needs to be displayed on the drone.

Operations in ‘Specific’ category may be conducted after the authorisation given by the National Aviation Authority. Based on:

1. The risk assessment and procedures defined by the EU Regulation
2. The predefined risk assessment published by EASA as an AMC

Drone user can start operating in limited ‘Open’ category till June 2022:

1. Drones with weight up to 2 kg may be operated up to 50 m horizontal distance from people;
2. Drones with weight up to 25 kg may be operated at 150 m horizontal distance of residential, recreational and industrial areas, in a range where reasonably it is expected that no uninvolved person is overflown during the entire time of the operation.

3.2.3 U-space Regulation

In addition to regulation on drones, EU is working on a regulatory framework for unmanned traffic management (UTM) system solutions that in Europe are called U-space. U-space is a set of services and specific procedures enabling a safe, efficient, sustainable and secure integration of UAS into airspace. These services rely on a high level of digitalisation and automation of functions, which enable complex operations with low human workload. SESAR JU predicts that by 2025 Very Low Level (up to 152 meters) drone operations will be 10 000 000 flights per year [182].

U-space is divided into four different levels of services ranging from Initial U1 services (registration, electronic identification and geo-awareness (here to fly and where not to)) to U4 full integration with manned aviation. U2-level services are mainly targeting the drone pilot, where U3-level services have a higher degree of automation and interface directly with the drone system. SESAR JU executive director presented U-space roll-out timeline in [182] in 2019. Current U-space services with initial timeline being worked on include:

- **U1 Level (2019+):**
    1. Registration
    2. E-identification
    3. Geo-awareness
- **U2 Level (2022+):**
    1. Drone Aeronautical Information Publication
    2. Geo-fencing provision
    3. Incident / accident reporting
    4. Weather information
    5. Position report submission sub-service
    6. Tracking
    7. Drone operation plan processing
    8. Emergency management
    9. Monitoring
    10. Procedural interface with ATC
    11. Strategic conflict resolution
    12. Legal recording
    13. Digital logbook
    14. Traffic information
    15. Geospatial information service

    16. Population density map
    17. Electromagnetic interference information
    18. Navigation coverage information
    19. Communication coverage information
- **U3 Level (2027+):**
    1. Collaborative interface with ATC
    2. Dynamic capacity management
    3. Tactical conflict resolution
- **U4 Level (2030+):**
    1. Full integration with manned aviation

Several European very large demonstration projects have shown that reliable, cost-effective and secure wireless data connections remains one of the key bottlenecks for the adoption of U-space. EASA (European Union Aviation Safety Agency) published on March 13, 2020 Opinion nr 01/2020 "High-level regulatory framework for the U-space" [103) and Appendix to Opinion 01/2020 [104]. The objective of this Opinion is to create and harmonise the necessary conditions for manned and unmanned aircraft to operate safely in the U-space airspace, to prevent collisions between aircraft and to mitigate the air and ground risks. Therefore, the U-space regulatory framework, supported by clear and simple rules, should permit safe aircraft operations in all areas and for all types of unmanned operations.

This Opinion contains a draft regulation and is submitted to the European Commission, which will use it as a technical basis in order to prepare an EU regulation [105] and Appendices 1, 2 and 3 to draft Commission Implementing regulation [106].

For information, EASA published the draft text for the related EASA decision that contains acceptable means of compliance (AMC) and guidance material (GM) [107]. The final decision that issues the AMC & GM will be published by EASA once the European Commission has adopted the regulation and once the necessary consultation with the affected stakeholders has been performed.

This Opinion is, therefore, a first regulatory step to allow immediate implementation of the U-space after the entry into force of the Regulation and to let the unmanned aircraft systems and U-space technologies evolve. The Opinion with appendices is published on EASA website [108]. EASA published also Terms of reference for rulemaking task RMT.0230 [109]. EC regulations regarding U-space are expected to enter into force in the second half of 2021.

3.2.4 National Future Regulatory Impacts

Finland Government proposes amendments to the Aviation Act that would supplement the revised EU regulation. The Government submitted its proposal to Parliament to amend the Aviation Act on 8 April 2020.

The amendments are based on the EU Regulation on common rules in the field of civil aviation and establishing of a European Union Aviation Safety Agency, the so-called EASA Regulation. The EASA Regulation and EU statutes issued under it are directly applicable in EU Member States. However, some degree of national flexibility will be allowed in matters such as light aviation and unmanned aviation, like drones.

Amendments are proposed to the obligation to maintain in force liability insurance. According to EU legislation, all unmanned aircraft over 20 kg must be insured. Regarding lighter unmanned aircraft, decisions on the obligation to take out a liability insurance can be made nationally. Finland Government proposed that the liability insurance obligation apply also to aircraft, excluding low-risk activities. The insurance should be standard liability insurance for damages.

It is also proposed that in future the Transport and Communications Agency could establish airspace zones to facilitate or restrict the use of unmanned aircraft. The Agency would also be responsible for market surveillance of unmanned aircraft.

The Government proposal has addressed the feedback received from the consultation round. Issues specified in the proposals include the insurance obligation and liability for damages in unmanned aviation and airspace zones facilitating or restricting the use of unmanned aircraft. The preparation was carried out in close consultation with interest groups [99].

In France and in Greece there is no information about activities regarding amendments for national aviation regulation.

4 ROLE OF 5G TECHNOLOGY

This section identifies key application areas where 5G technology can help provide new or enhanced services, and how each stakeholder in the UAV-service-related value chain (UAV equipment vendors, vendors of telecommunications equipment, network operators, UAV service providers, regulatory bodies), and the society at large, can benefit from these developments. Figure 28 gives a graphical overview of vertical industries where the 5G technology is expected to significantly impact and the Aeronautical domain is a key present consideration.

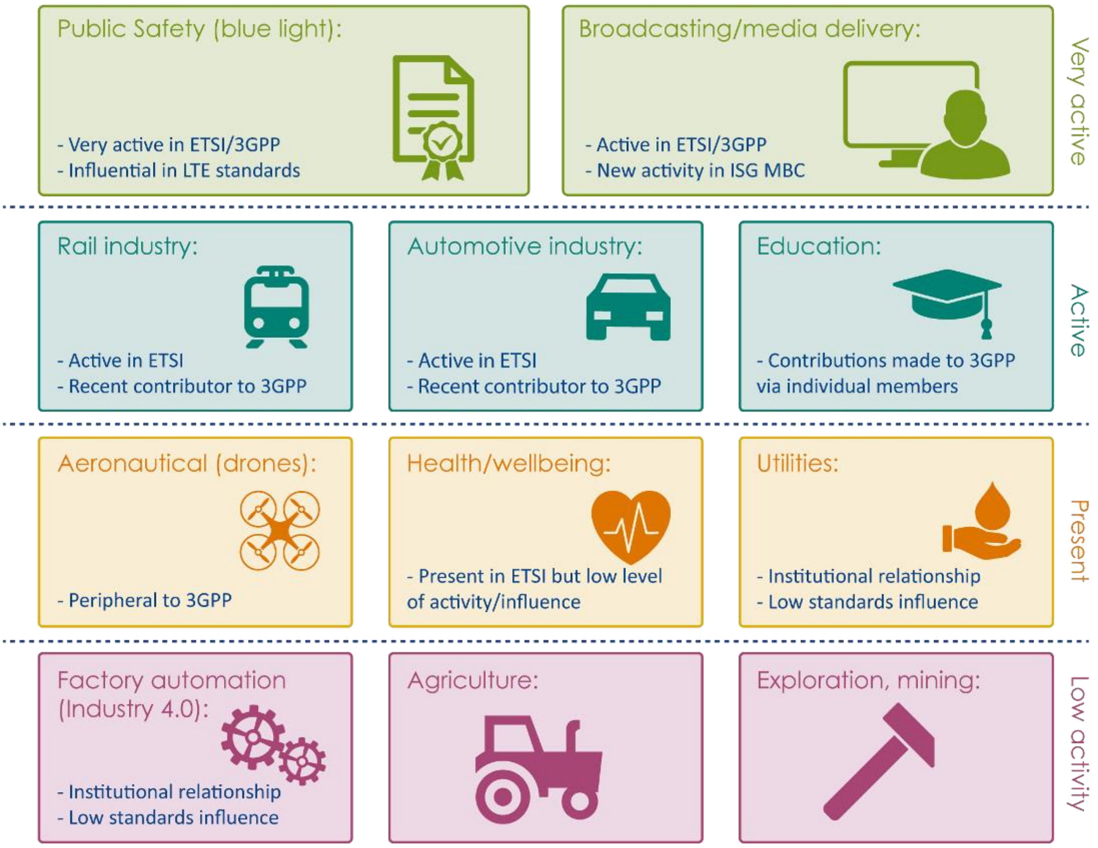


Figure 28 Who is interested in using 5G? [110]

There are several major problems that the drone/UAS industry is currently faced with, such as limited operation range, crowded, interference on un-licensed spectrums, limited bandwidth that cannot guarantee real-time high-definition (HD) image/video transmission, inaccurate tracking. Mobile networks can help to overcome the aforementioned issues faced by the drone industry through providing capabilities such as remote and real-time control, HD image/video transmission, efficient drone identification and positioning.

In fact, 5G-enabled mobile networks are expected to introduce new technologies to provide 3D coverage enhancement, high data rate, low latency, customized end-to-end quality-of-service (QoS) guarantee, and efficient identification and monitoring.

As depicted in Figure 29 Leading the world to 5G: Evolving cellular technologies for safer drone operation [111], collaboration of network, regulation and technology stakeholders is key to significantly advance drone industry developments.

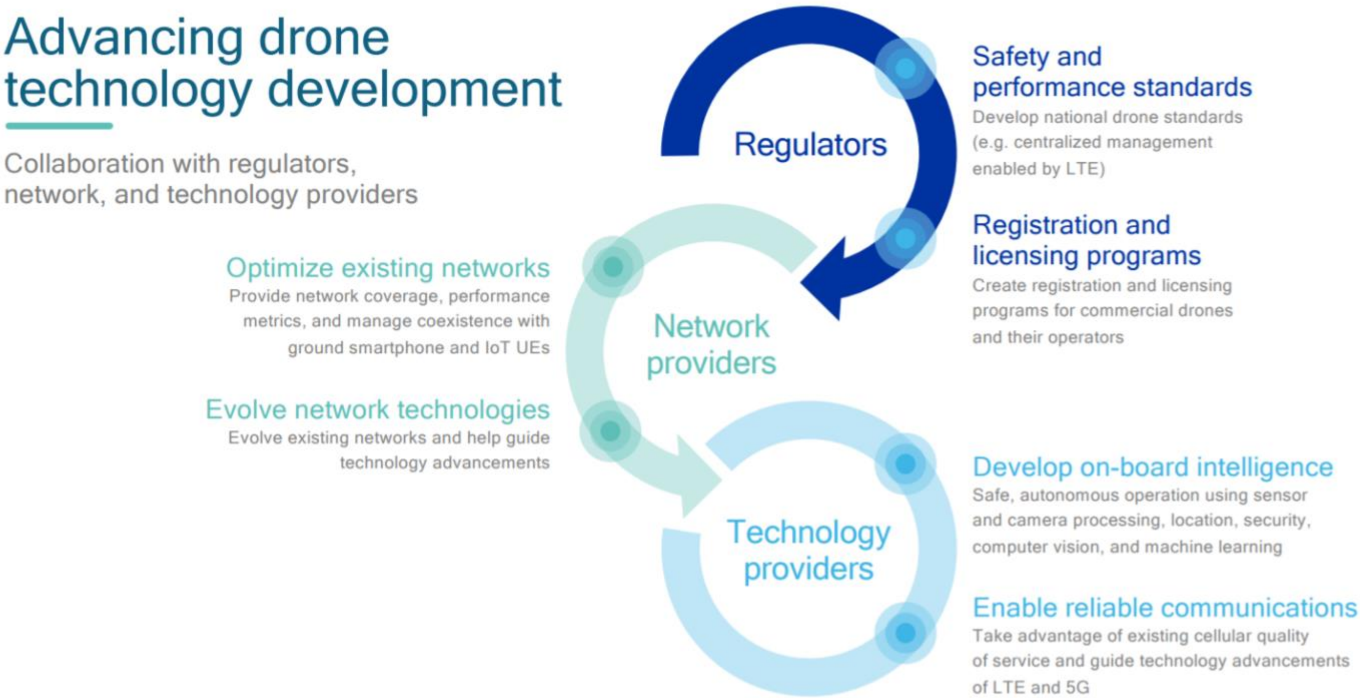


Figure 29 Leading the world to 5G: Evolving cellular technologies for safer drone operation [111]

4.1 Standardization of 5G Networks for UAVs Support

ITU Radio Communication Sector (ITU-R) has performed their study on IMT-2020 system (ITU-R M.2083) where new targets for various criteria have been elaborated and agreed. They refer to: much higher peak and user-experienced data rates, higher spectrum utilization efficiency (more efficient modulations), much higher mobility (considered as supported of speed of mobile terminal in motion, up to very high speed trains), significantly lower user data transmission latency in radio layer (for real-time processes support), much higher connection density (i.e. amount of supported terminals per unitary area – to support massive scale of connected devices), much improved network energy efficiency (it is impossible to sustain the network capacity growth by delivering power at the same growth ratio, taking into consideration the global power consumption for networks and demands for energy savings) and finally the much higher area traffic capacity (due to combined data rate and connection density growths). The visual comparison of LTE and 5G capabilities is presented in Figure 30.

In the same document, ITU-R also distinguished and defined three basic classes of services with distinct characteristics: eMBB (enhanced Mobile Broadband – addressed to high data rate multimedia services), uRLLC (Ultra Reliable and Low Latency Communication – industrial applications) and mMTC (massive Machine-Type Communication – massive scale Internet of Things). This classification has been widely adopted by the telco industry.

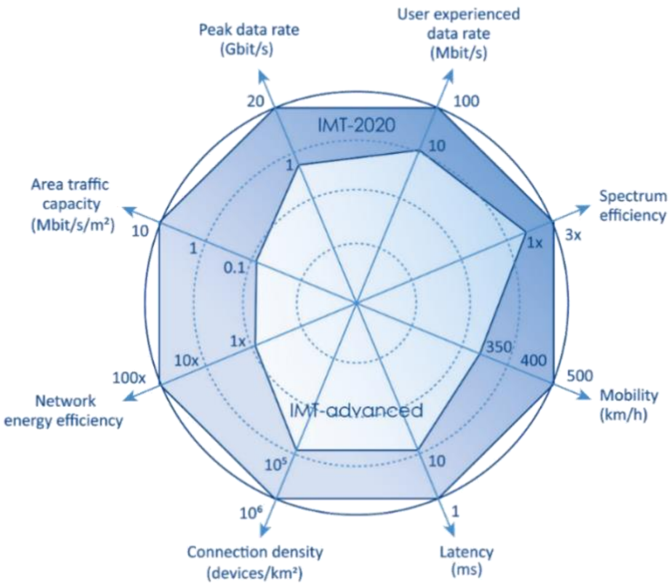


Figure 30 Comparison of key capabilities of IMT-Advanced (4th generation) with IMT-2020 (5th generation) according to ITU-R M.2083 [110]

The European Conference of Postal and Telecommunication Administrations (CEPT) has identified existing Mobile Fixed Communications Network (MFCN) bands as a potential means to provide connectivity to UAS via existing LTE mobile networks for command and control links. It is also evaluating the current regulatory framework for MFCN bands for this use case. One possibility for professional UAS applications is to use existing mobile MFCN networks to provide connectivity to UAS by usual (unmodified) mobile networks with LTE technology provided that the command and control link(s), where appropriate, meet the relevant aviation safety requirements prevalent in the country of concern. This can be realised either by an external LTE device attached to UAS or in future by implementing SIM-cards installed within UAS. Such a connectivity could be used both for serving the payloads such as video or other collected data via sensors and for the command and control function of UAS [112].

In Europe, there is a fast-growing demand to operate Unmanned Aircraft Systems (UAS) under beyond-visual-line-of-sight (BVLOS) conditions mainly for professional purposes. To enable these intended range of use cases there is the need for communication links between the UAS, its operator and an intended UAV Traffic Management (UTM) system. The purpose of this ECC Report nr 309 is to evaluate the use of Mobile Fixed Communication Networks (MFCN) for the communication links of Unmanned Aircrafts (UAs) within the current MFCN spectrum harmonised regulatory framework for the different MFCN bands, including potential impact of such use on MFCN networks and other systems and services and possible regulatory considerations.

The intention is to use already existing MFCN BSs which are typically deployed to provide effective coverage at ground level. At this stage, mobile operators do not intend to develop specific network planning to respond to these new usages. Due to this, coexistence studies are mostly required for uplink due to the elevated position of aerial UEs. No specific studies are required in the downlink for non-AAS (Active Antenna Systems) base station, since the emissions characteristics are not modified. Studies in the downlink would only be required for the case of AAS-Base Station, where beam steering may lead to beam pointing above the horizon and may modify the emission characteristics [113].

Cellular-Connected UAVs is a promising technology that can become a reality in the near future. Enabling ultra-reliability, low latency and high data rates are important issues to guarantee ubiquitous communications between UAVs and GCS/Users regardless of their locations. The main advantages of using cellular-connected UAVs compared to the traditional Ground-to-UAV communications can be summarized as follows:

- **Ubiquitous accessibility**. Thanks to the almost ubiquitous accessibility of cellular networks worldwide, cellular-connected UAV makes it possible for the ground pilot to remotely command and control (C2) the UAV with essentially unlimited operation range.
- **Enhanced performance**. With the advanced cellular technologies and authentication mechanisms, cellular-connected UAV has the potential to achieve significant performance improvement over the simple direct ground-to-UAV communications, in terms of reliability, security, and communication throughput.
- **Ease of monitoring and management**. Cellular-connected UAV offers an effective means to achieve large-scale air traffic monitoring and management.
- **Robust navigation**. Traditional UAV navigation mainly relies on satellite such as the Global Position System (GPS), which is however vulnerable to disruption of satellite signals due to, e.g., blockage by high buildings or bad weather conditions. Cellular-connected UAV offers one effective method, among others such as differential GPS (D-GPS), to achieve more robust UAV navigation by utilizing cellular signals as a complementary for GPS navigation.
- **Cost-effectiveness**. Cellular-connected UAV is also cost-effective. On one hand, it can reuse the millions of cellular base stations (BSs) already deployed worldwide, without the need of building new infrastructures dedicated for UAS alone, thus significantly saving the network deployment cost. On the other hand, it may also help saving the operational cost, via bundling UAV C&C and other numerous types of payload communications into cellular systems, which will create new business opportunities for both cellular and UAV operators [114].

Connectivity over mobile networks has a lot of advantages for the UAS ecosystem:

- The mobile network can be a part of UTM solutions;
- The general identification and registration schemes for mobile UEs (IMSI, IMEI) can be used for UAVs identification and registration in connected systems;
- The mobile network can assist law enforcement by enabling identification and tracking of drones, as well as no-flight zones.
- The mobile network ensure transmission reliability, privacy and data protection.

3GPP is actively leading technical studies and standards related to 5G usage by UAVs. 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 (AKA drones) and UAV controllers under the watchful eye of UTM.

As 5G use cases have evolved, new studies and new features are needed, for the safe operation of UAVs, but also to ensure that other users of the network do not experience a loss of service due to their proximity to Unmanned Aerial Systems [115].

The foundations of UAS communication services support by the 3GPP 5G system (5GS) are primarily in definition of the 5GS architecture [174] followed by definition of 5GS procedures [176], which provide various concepts and functions important for UAS. First of all, network slicing (NS) is an inherent part of the 5GS vision. Until now, the mobile network was built as a universal network, supporting services with very divergent characteristics in a uniform manner. As a result, the compromise did not sufficiently satisfy the requirements of any of them. The LTE network operating in this logic will be replaced by a federation of parallel virtual networks, each of which is individually tailored to the requirements of different classes of services defined by ITU-R and followed also by 3GPP. This way, the traffic belonging to different communication links (C2, real-time video, sensors etc.) will be directed to the right network, which will transmit and process it through the User Plane Function (UPF) in the best possible way.

The support of NS within the 5GS includes network slice instance (NSI) selection and admission control on per-user level (identified by IMSI). Currently, it is assumed that a 5G terminal can be attached to maximum 8 different NSIs of the same network operator, which is considered as an adequate number for typical usage scenarios. The User Plane (UP) in the 5GS is no longer just a user traffic tunnel anchored at the Packet Data Network (PDN) gateway, with user mobility provided. The UPF is now a service- and/or network slice-specific chain of functions processing the user traffic (e.g. firewall, Deep Packet Inspection – DPI, packet classification, redirection and alteration), i.e. the functionalities of SGi LAN in 4G are now incorporated to the 5GS UP.

All 5GS entities (UE, RAN, Core Network and also MEC, if exists) have to be NS-aware. In 4G and earlier generations, the UE requested only an access to specific Packet Data Network identified by its APN. In 5G UEs will specify also a path to this data network, i.e. request an access to specific NSI with a commonly recognized identifier. In case the requested NSI is unavailable in the specific area (due to inexistence or congestion), the 5G network will have to substitute the requested NSI with the best possible alternative.

The 5GS supports classification of traffic for QoS assurance. The standardized 5QI (5G Quality Identifiers) used for stamping of traffic are a significantly extended 4G QCI (QoS Class Identifier) list. The 5QI definition contains currently 27 classes with processing types (guaranteed bit rate, non-guaranteed bit rate, delay-critical guaranteed bit rate) and allocated default priority level, E2E packet delay budget, allowed packet error rate; default maximum data burst volume (maximum size of user data in a packet); default averaging window (timeframe for measuring e.g. error rate) and example applications.

The architecture of 5GS Control Plane (CP) is designed according to service-oriented principle, which makes it easy to expand the CP functionally and enable new features. Additionally, the number of protocols used for exchange between the CP functions has been consolidated and now the protocol for interactions between all control-plane entities is HTTP instead of previously used telecom operator specific ones like Diameter or GTP-C (GPRS Tunnelling Protocol Communication). The CP functional applications will be designed as stateless ones, i.e. the state of each network procedure will be stored centrally and e.g. session request may be successively processed by various instances of the same CP application without a need of troublesome transferring a context to be able to complete a procedure.

Among other functions, the 5G CP includes Network Slice Selection Function (NSSF), Session Management Function (SMF) – a UPF control agent and Application Function (AF) – the way to embed external or service-augmenting functions within the 5GS CP, Network Data Analytics Function (NWDAF) – mobile network monitoring centre (able also to analyse and alert threshold crossings), Network Exposure Function (NEF) – an access gateway to CP functions for external environment.

Apart from general 5GS architecture framework mechanisms, which are of importance for UAS support, the 3GPP also works on issues specific to UAS support by the 3GPP system:

- **TR 36.777** [169] – this study concerned the analysis of various aspects of UAS support in LTE networks. The conclusions are mainly focused on the issue of interferences mitigation, to a lesser extent on mobility performance and aerial UE identification.
- **TS 22.125** [170] – this technical standard defines a variety of UAS use cases and their requirements (aviation domain-related, including C2, UTM and remote identification, as well as specific to drone usage), especially functional and in terms of performance targets: data rates, E2E delays, reliability rates, allowed altitudes above ground levels and ground speeds and positioning latencies/accuracies.
- **TS 22.261** [173] – this technical standard provides supplementary information, as it is dedicated to general 5G service use cases and requirements. Despite the fact that the UAS support area has been excluded from it and moved to the separate aforementioned document [TS 22.125], here the overall picture is complemented (e.g. tampering detection and prevention).

- **TR 23.754** [171] – this architectural study follows the standardized requirements for UAS connectivity, identification and tracking, and analyses necessary enhancements for their support. The document is at infancy, but it already provides the architectural vision of the aviation ecosystem containing UAS components, UTM, authorized 3rd parties (e.g. police, aviation authorities) and the 5GS. The vision outlines interfaces for these actors' interaction with 5GS steering mechanisms in the 5GS CP.
- **TR 23.755** [172] – this report of the architectural study on application layer support for UAS is also at the early draft stage and currently deals with:
  - applicability and possible needs for enhancements of service enabler architecture layer (SEAL – set of functions for management of location, group, configuration, identity, key and network resources) – common to all vertical industry applications – for UAS services;
  - broadcast communication amongst UAVs both in off-network and on-network scenarios;
  - UAV location information – both verification of location reported by UAV, which cannot be fully-trusted, by the 3GPP network and possible supplementing of 3GPP system-based location information to the location reporting towards UTM;
  - UAS services capabilities exposure – real-time monitoring of the UAV status information (e.g. location of UAV, communication link status) and exposure to a 3rd party of the information about UAV service status in a certain geographical area and/or at a certain time.

It should be noted that the technical standards are normative documents, while study reports provide concepts or proposals which after further validation may be incorporated to normative documents. Hence, the 3GPP support needs standardization of functionalities and mechanisms, which will respond to already standardized UAS services requirements.

The IEEE ICC workshops have covered the following topics in previous years 2019-2020, highlighting key topics related to the integration of UAVs and 5G. These are:

- Channel measurement and modelling for UAV-BS/UAV-terminal/UAV-UAV communication links
- Network architectures and communication protocols for UAV communications
- Spectrum management and multiple access schemes for cellular-connected UAVs
- Interference mitigation for cellular-connected UAVs
- Massive MIMO/millimetre wave communications for cellular-connected UAVs
- 3D aerial BS placement and online/offline UAV trajectory optimization
- Joint trajectory design and resource allocation for UAV communications
- Energy consumption model and energy supplying methods of UAVs
- Energy-efficient UAV communications
- Theoretical frameworks for the analysis of UAV communications
- System-level simulation studies of UAV communications
- Cyber security and physicals security of UAV communications
- Machine learning for UAV communications
- Experimental performance demonstrations, prototyping, and field-tests of UAV communications
- Standardization progress
- Economical frameworks for UAV communications, e.g., cost studies, business models, etc.

- Regulatory schemes for UAV communications, e.g., safety operation, privacy protection, etc [132].

4.2 5G Radio Frequency Communications and Spectrum Allocation

The wireless RF communication needs also considerations of spectrum management strategy as well as phenomena associated with propagation of radio waves and effects of mutual interferences of emissions from multiple sources.

The following aspects are widely believed to be relevant to the choice of mobile networks' spectrum management strategy [116]

1. Usage of licensed spectrum for mobile network enables widespread connectivity with high quality and capacity to support UAV services with rising usage and requirements' levels.
2. Worldwide or at least regional harmonization of licensed mobile spectrum can support affordable UAV connectivity worldwide (cheap equipment due to massive scale of production) and hence stimulate growth of UAV market. Additionally, such harmonization supports interoperability and trans-border scenarios (e.g.) [117].
3. The regulatory policy should not introduce unnecessary barriers to using licensed mobile spectrum for UAVs connectivity, otherwise the significant benefits of cellular connectivity to UAV sector will be damaged.
4. Service and technology neutral framework should be adopted by regulators to fully support UAVs [116].

In relation to the definition of an individual authorisation opportunity for professional use of UAS, this needs to be defined by the national administration, taking into account national circumstances.

The communications links that are considered in this report deal with command and control and possibly support for sense and avoid. It could be necessary to add a downlink video stream as an essential requirement of the safe operation of a UAS.

A possible solution for small-size professional UAS would be if the command and control as well as the payload (usually video, sometimes data) could be communicated within the same frequency band because the capacity for carrying multiple radios on a UAS is limited. In consequence, the radio equipment installed in the UAS may need to be one system for command and control as well as the payload information.

For the payload information, there is much more capacity needed for downlinking video information than, for example, uploading commands to configure the payload of the UAS.

The selected frequency bands and the associated regulation should be able to support the spectrum need for the control of UAS but also include some provisions to allow payload links. The associated regulation should also make it possible to share the frequency band or bands between these two usages for countries wishing to do so, while on one hand ensuring that the payload resource, unlike command and control, is not subject to aeronautical safety constraints and on the other hand that the payload does not use the control resource and thereby compromise the safety of the UAS [118].

April 10, 2018 ECC mandated ECC PT1 to draft an ECC report by March 2020 in order to evaluate the use of the MFCN for the command and control and payload links of UAS within the current MFCN harmonised regulatory framework for the different MFCN bands below 3.8 GHz, including potential impact of such use on MFCN networks and other systems and services and regulatory considerations. Based on initial conclusions from ECC Report 268 and 3GPP Study Item TR 36.777 on impact of the drones on the MFCN bands, it is proposed to list different scenarios to assess the interference from aerial UE on other MFCN networks in adjacent channels and service from adjacent bands. In 3GPP report (3GPP TR 36.777), the technical feasibility for drones to be served by existing terrestrial LTE networks has been demonstrated and in ECC Report (ECC REP 268), the operational role of the MFCN

to offer end-to-end solutions for drones (registration, identification, geofencing, tracking, privacy, data protection, coverage for command & control or payload communications for some categories of drones) has been recognised [119].

In 5G networks, radio spectrum will be required to support services ranging from narrow-band IoT, through enhanced mobile broadband (eMBB) and fixed-wireless access (FWA), to ultra-high-speed and extremely low latency connectivity. As depicted in Figure 31 5G spectrum band classes and use cases [11]

5G spectrum band classes are associated as appropriate per use case.

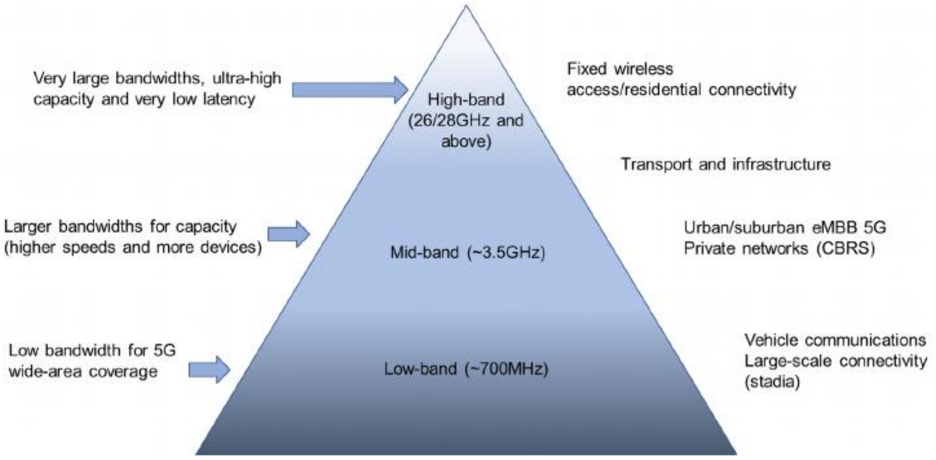


Figure 31 5G spectrum band classes & use cases [11]

In fact, 5G radio spectrum is categorized into the following two different frequency ranges [167, 168], which have capacity and performance characteristics that suit some service models better than others. Specifically:

- **Frequency Range 1 (FR1)** covers spectrum offerings from 410 MHz to 7125 MHz and can be further divided into the following sub-band categories:
  - ***Sub-1 GHz*** that supports widespread coverage across urban, suburban and rural areas, and
  - ***1-6 GHz*** that offers a good mixture of coverage and capacity benefits.
    - This includes spectrum within the 3.3-3.8 GHz range which is expected to form the basis of many initial 5G services. The 3.4-3.6 GHz range is almost globally harmonized, which can drive the economies of scale needed for low-cost devices.
    - It also includes others which may be assigned to, or reframed by, operators for 5G including 1800 MHz, 2.3 GHz and 2.6 GHz, etc. In the long term, more spectrum is needed to maintain 5G quality of service and growing demand, in bands between 3 and 24 GHz.
- **Frequency Range 2 (FR2)** includes frequency bands from 24.25 GHz to 52.6 GHz and is needed to meet the ultra-high broadband speeds envisioned for 5G. Currently, the 26 GHz and/or 28 GHz bands have the most international support in this range. During the World Radio Communication Conference 2019 (WRC-19), which took place in Sharm El-Sheikh, Egypt, over four weeks from 28 October to 22 November 2019, additional bands for IMT identified in the 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 and 66-71 GHz bands, facilitating development of the fifth generation (5G) mobile networks. However, it should be noted that radio access in FR2 has an effective coverage radius of a few hundred meters maximum. Hence, the high capacity of 5G network in FR2 is achieved at the expense of high density of base stations.

From the latest published version of the 3GPP TS 38.101 [167, 168] list the specified frequency bands and the channel bandwidths supported for FR1 and FR2 equivalently as depicted in Annex 1, Annex 2.

One of the prioritized areas in 3GPP release 17 is 52.6-71 GHz spectrum, which will provide more bandwidth, but small-area coverage to UAVs [120].

It should be noted that the European Union has taken a number of decisions designed to promote availability of new spectrum bands for 5G and ensure harmonization of suitable spectrum for 5G. In January 2019, the European Commission adopted an Amending Implementation Decision to harmonize radio spectrum at 3400–3800 MHz (the 3.6 GHz band) for future use with 5G.

- The band had already been harmonized for use for wireless broadband services.
- The new Decision updated the technical conditions to support 5G deployment.

In May 2019, the European Commission adopted an Implementing Decision [121] to harmonize radio spectrum in the 24.25–27.5 GHz (26 GHz) band, enabling Member States to set common technical conditions for use of the band and open it up for use (with 5G in mind, but on a technology- and service-neutral basis). However, the usage of 24.25-27.5 GHz band for ground-UAV (i.e. downlink) communication has been prohibited due to possible impact on existing satellite receivers in the FSS and ISS; while UAV-ground (i.e. uplink) communication is still allowed.

In addition, given that there will be a need to adapt the harmonized regulatory framework of Mobile/Fixed Communications Networks (MFCN) in the frequency bands ranging from 694 MHz to 3.8 GHz to account for 5G (e.g. to accommodate the needs of networks based on small cells and Active Antenna Systems). CEPT ECC conducted technical analysis for the 900 & 1800 MHz bands in the *ECC Report 297* and the 2.1 GHz band in the *ECC Report 298*, which were published in March 2019. Similar analysis for the 2.6 GHz band is provided in the *ECC Report 308* (March 2020), and an update to the *ECC Decision (05)05* was agreed in July 2019.

In the CEPT roadmap for 5G in Version 9, amendment proposed by WG FM #95, February 2020 that 40.5-43.5 GHz and 66-71 GHz may at future be harmonized in Europe.

Additionally, the *ECC Report 309* (draft, planned to be approved by ECC plenary meeting which will take place in July 2020) provides the analysis on use of MFCN for the command & control and payload links of UAVs within the current MFCN harmonised regulatory framework. The document studies an impact of aerial UEs on servicing MFCN and also their coexistence, while operated through MFCN, with other services in-band and in adjacent bands for the following bands: 700 MHz, 800 MHz, 900 MHz, 1500 MHz, 1800 MHz, 2 GHz, 2.6 GHz, 3.6 GHz and 26 GHz.[113].

One of the most important issues for using 5G as a communication platform for UAVs is the interference problem. Meter and shorter waves propagate in a line-of-sight manner according to horizontal propagation (transmission range depends on the height above the ground level). The mobile network mechanisms of interference management are adapted to ground-based terminals. Mass emergence of 5G UEs carried by drones at heights of several dozen meters or more requires serious consideration of interferences caused by on-board UEs (higher impact radius) as well as the sensitivity of drones' UEs themselves to signals of distant gNBs, which would be non-receivable on the ground. Additionally, the gNBs antenna systems' radiation patterns cause the phenomenon of very high variability of coverage and cell association patterns when changing the height of UAV above ground level. In [122] the results of cell association patterns simulations based on maximum received power at different levels above ground level in rural macro LTE network have been presented (see Figure 32 Simulated cell association patterns at different altitudes in rural macro LTE network [123]

While at the ground level and at 100 m the association patterns are regular and similar, at 50 m they are very chaotic and at 300 m the pattern of antenna radiation side-lobes (concentric curves of circles' slices) is clearly visible. Hence, two main problems exist: (1) line-of-sight propagation causes high levels of interference from many neighbour cells at UAV operational altitudes, as well as from ground UEs, which entails potential difficulties in establishing and maintaining connection to the network; (2) default

mobility procedures may be too slow for successful execution as the UAV moves – especially with relatively high velocities – through highly variable cell association patterns, especially crossing side-lobe nulls of base station antennas.

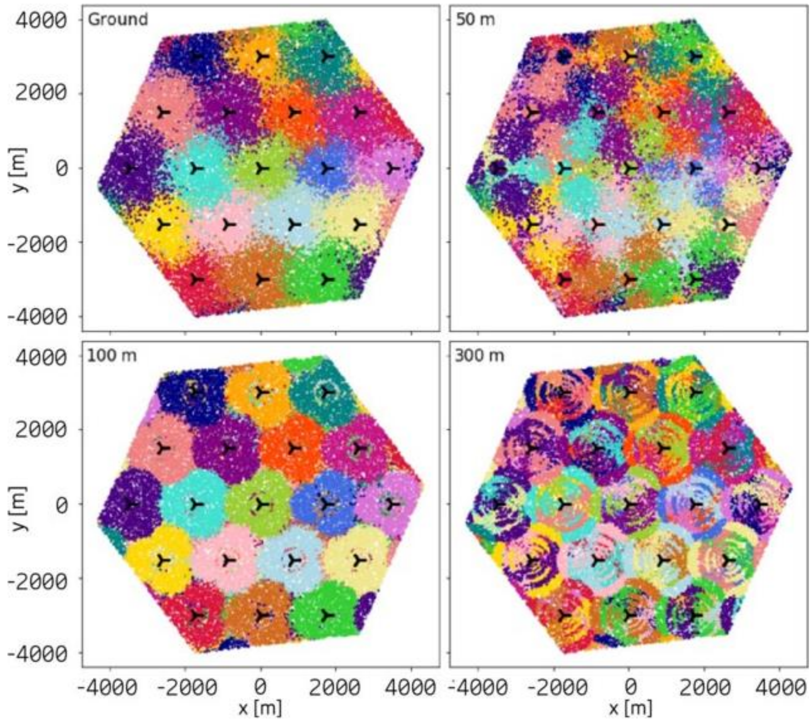


Figure 32 Simulated cell association patterns at different altitudes in rural macro LTE network [123]

The currently used techniques for interferences mitigation (see Figure 33) at the ground level include inter-cell coordination of spatial-temporal frequency channels allocation to base stations (various schemes possible), interference suppression techniques at the receiver side or dynamic adjustment of transmission power (the power is lowered to the minimum level providing sustained QoS, which also prevents excessive mobile terminal battery draining). They are primarily focused, however, in prevention of signal quality degradation and instability in cell border areas, not in interaction of distant cells or terminals located in distant cells. For UEs on-board UAVs the following additional interferences management techniques can be applied (separately or in conjunction):

- Coordinated multipoint technique – transmission base stations cooperate in scheduling to strength the received signal and mitigate inter-cell interference and the scheduling decision is based on the coordination among UAVs; as UAVs receive interfering signals from more ground transmitters (base stations and terminals) and their transmitted signals are receivable by more ground receivers, this technique must involve a larger set of cells and hence the complexity of the coordination problem increases.
- Enhancement of receiver-side techniques in aerial UEs by adding more antennas compared to handheld terminals or using terminal-side beamforming with MIMO antennas to provide spatial selection of received signal. At the same time, using a directional beam for transmission will significantly decrease the spatial impact of interferences caused by the UAV.
- Partitioning of radio resources to ensure ground and aerial traffic separation, so that these fractions are served with disjoint radio resources. Static resources reservation will cause utilization inefficiencies, therefore UAVs position tracking for dynamic radio resource management is needed.
- Base station-side beamforming with dynamic tracking of served UAVs trajectories.

- More advanced power control techniques based on optimized power control parameters help to reduce interferences generated by UAVs.
- Dedicated cells for serving UAV traffic with directional antennas pointed upwards instead of down-tilted. Such cells may be a good option in the areas of frequent and dense UAV take-off and landing operations.

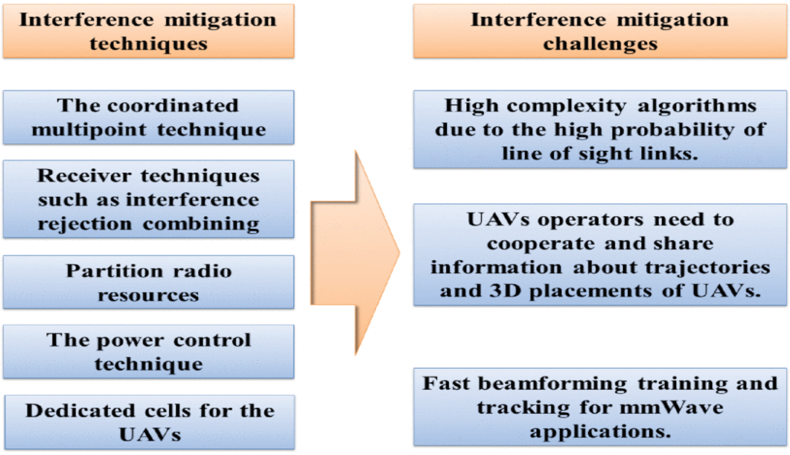


Figure 33 Interference mitigation techniques and challenges [124]

ECC Report nr 309 (2020) studies in ANNEX 3 and ANNEX 17 show that the interference from aerial UEs in adjacent channel is negligible compared to the case of adjacent interference caused by ground UEs.

This trend can be explained by:

For higher bands (above 1 GHz), coexistence and sharing studies are required for both:

- Uplink (UL), due to the location of 4G and 5G aerial UEs compared with usual UEs on the ground;
- Downlink (DL) for base stations leveraging AAS antennas. Studies are not required for the DL of non-AAS BSs.

The studies below consider only non-AAS base stations, except in the case of the 3400-3800 MHz band [125].

3GPP study TR 36.777 suggests that the number of airborne UEs supported by the network should not exceed 33% of the total number of UEs in cell. The impact of aerial UEs on UL and DL performance remain modest when the percentile of aerial UEs (compared to total number of UEs) remain low.

Taking into account both theoretical studies and practical considerations, it can be concluded that many potential coexistence issues can be resolved through implementation of measures at national level for terminals operating in the 703-713.5 MHz frequency band through a no-fly zone around RAS sites, or alternatively measures (e.g. additional filtering) to reduce second harmonics, if appropriate.

With respect to aerial UE and interference to DTT (Digital Terrestrial Television) receivers the primary concern is aerial UE using the 700 MHz band and flying below 30 m above ground level (AGL) - e.g. delivery drones. Aerial UE flying higher than 30 m away from populated areas or using LTE frequency band 800 MHz or above should not be a problem to reception of DTT [126].

ECC noted that additional regulatory measures required for minimising interference with TV antennas and Fixed-Satellite Service (FSS) antennas:

- 700 MHz band is: aerial UEs operating in this band should fly at least 30 m above ground level (to ensure minimum distances from roof-top antennas vertically 8.5 m and horizontally 22 m).

- 3400-3800 MHz band: to avoid the need for specific protection distances associated with each FSS antenna the unwanted emissions of an aerial UE would need to be lower than -60 dBm/MHz.

To ensure visibility for UAs market development in relevant MFCN bands while ensuring confidence of all spectrum users, there is a need for harmonised spectrum regulatory conditions for “aerial UEs: aerial UEs installed on UAs and manned aircrafts” usages in the relevant suitable MFCN bands [127].

The conclusions of ECC Report 309 studies on the conditions of use of drones in the frequency bands 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2 GHz, 2.6 GHz and 3.5 GHz open promising prospects for this type of applications. The constraints remain moderate and linked to the protection of certain uses in the adjacent strip:

- In the 700 MHz band, drones will have to fly more than 30 meters from the ground in order to avoid interference to TV broadcasting receivers.
- National conditions will have to be established to protect earth stations in the 3.4-4.2 GHz bands (based on minimum radius of UAV or antenna ERP).

Studies have therefore shown that enough frequencies would be usable for communications with long-range drones, including when roaming. This work will make it possible to define harmonized conditions for the use of these drones in Europe. Each frequency manager will then set up national rules and then authorization frameworks [128].

It should be noted that interference mitigation is complex problem and solutions come via 3GPP specifications in 2020-2021, where network operators and device vendors (Nokia, Ericsson etc.) participating actively.

3GPP Release 16 Stage 3 freeze is planned in June 2020 and it describes related to UAV services:

- Interference mitigation,
- Location and positioning.

Release 17 is planned for delivery in September 2021, with some prioritised areas are particularly relevant for 5G!Drones. These topics mainly relate to UAV and UTM integration into 3GPP systems:

- Aerial UE-specific reporting, such as height, location and flight path reporting.
- Remote identification, including UAV-UAV, UAV-ground identification and tracking;
- UAV connectivity requirements and enhancements;
- UAV restrictions [120, 177].

4.3 5G Roll-out and Services for UAVs

Regulators around the world are actively developing their 5G spectrum plans and some have completed the first assignments. The key focus is on new mobile bands including spectrum in the 3.5 GHz range (i.e. 3.3-3.8 GHz) that has been assigned in numerous countries. But other bands are also being considered. For example:

- Several countries plan to use spectrum in the 4.5-5 GHz range for 5G, including China and Japan;
- A growing number of countries are considering the 3.8- 4.2 GHz range, and 5925/6425 – 7125 MHz;
- There is also interest in assigning the 2.3 GHz and 2.5/2.6 GHz bands for 5G [129].

5G spectrum auctions already took place in the three pioneer bands for 5G; all in all, at EU level, 13 countries have assigned spectrum for 5G in one or two bands.

- The 700 MHz band has been assigned in 7 EU Member States so far including Denmark, France, Finland, Germany, Hungary, Italy and Sweden.
- The 3.4-3.8 GHz band has been assigned in 9 EU MSs, in Austria, Czech Republic, Finland, Germany, Hungary, Ireland, Italy, Latvia, Spain and in the United Kingdom.
- The 26 GHz band has been assigned in Italy.

Exceptional circumstances caused by the Covid-19 epidemic have forced some countries in Europe to postpone 5G auctions scheduled in the first months of 2020. Four EU countries, Austria, France, Spain and Portugal have postponed spectrum auctions for 5G due to the Covid-19 epidemic so far (03.04.2020) [130]. In Greece, a tender involving the frequency bands of 700 MHz, 2.1 GHz, 3.4-3.8 GHz and 26 GHz is planned to take place by the end of 2020. Finland and France plan to continue with auctions of 700 MHz, 3.4-3.8 GHz and 26 GHz in the near future [131].

Unmanned aerial vehicles (UAVs) have found fast growing applications during the past few years. In June 2016, the Federal Aviation Administration (FAA) of the United Sates released the operational rules for routine commercial use of small-unmanned aircraft systems (UAS), which will further spur the fast growth of the global UAV industry in the coming years. As such, it is imperative to develop innovative communication technologies for supporting reliable UAV command and control (C2), as well as mission-related payload communication. However, traditional UAV systems mainly rely on the simple direct communication between the UAV and the ground pilot over unlicensed spectrum (e.g. ISM 2.4 GHz), which is typically of low data rate, unreliable, insecure, vulnerable to interference, difficult to legitimately monitor and manage, and can only operate within the visual line of sight (LoS) range.

To overcome the above limitations, there has been significant interest in integrating UAVs into cellular communication systems. On the one hand, UAVs with their own missions could be connected into cellular networks as new aerial users. Thanks to the advanced cellular technologies and almost ubiquitous accessibility of cellular networks, cellular-connected UAV is expected to achieve orders-of-magnitude performance improvement over the existing point-to-point UAV communications. It also offers an effective option to strengthen the legitimate UAV monitoring and management, and achieve more robust UAV navigation by utilizing cellular signals as a complement to GPS (Global Position System).

UAV communications are significantly different from conventional communication systems, due to the high altitude and high mobility of UAVs, the unique channel of UAV-ground links, the asymmetric quality of service (QoS) requirements for downlink C2 and uplink mission-related data transmission, the stringent constraints imposed by the size, weight, and power (SWAP) limitations of UAVs, as well as the additional design degrees of freedom enabled by joint UAV mobility control and communication resource allocation.

Mobile networks can be used to support UAVs usage, which currently generally connected to a ground control system via short-range communications over unlicensed spectrum. This way, the mode of use is VLOS only and use cases (especially in enterprises) are highly limited. To enable BVLOS use cases, more scalable, reliable and secure connectivity is required, which can be provided by mobile networks [133]. As mobile networks provide omnipresent wireless IP connectivity, they are a versatile communication environment to be easily used for very diverse use cases, both in terms of aviation-related transmission and non-aviation data sources of completely divergent characteristics. Additionally, versatility of mobile networks supports also the development of new services for UAV.

Table 12 summarises the mobile assets and capabilities that can be used to enhance the performance of UAV and improve safety.

Table 12 Mobile assets and capabilities for UAVs [134], [135]

Asset	Description
Standardised and scalable solution for worldwide connectivity	Globally available, mobile networks provide very cost-efficient solutions: no investment is necessary to roll out a new infrastructure. In addition, mobile networks continue to evolve to match the evolving needs of UA communication platforms.
Licensed spectrum	Working with dedicated spectrum in licensed bands enables mobile networks to provide the reliable connectivity required for mission-critical applications, especially in BVLOS cases and in high-risk environments.
Secure communication channel	Mobile networks provide specific encryption mechanisms to protect communications against misuse, achieving high standards of data protection and privacy.
Lawful intercept and location verification	Mobile networks can support the lawful intercept of communications from the UAV, as they do with mobile devices. Mobile operators can also provide independent verification of the location of the UAV for use by the UAS (Unmanned Aircraft System) traffic management.
Trusted identification	The credentials established for mobile network authentication can meet the need for unique and trusted identification of UAV.
High data rates	Mobile networks enable achieving up to 10 Gbps in UL and 20 Gbps in DL in case of eMBB transmission, i.e. 10× to 100× improvement over 4G and 4.5G networks. Very high data rates can be an essential part of UAV services incorporating high quality video streaming e.g. 4K FPV video on-board of a drone.
Ultra-low latency	Guaranteed latency depends on the type of the transmission: of 1 ms for URLLC and 4 ms for eMBB transmission types;
Large area traffic capacity	5G network supports area traffic density up to 10 Mbps/m_2 thus enabling operation of more UAVs in the area
High reliability	Mobile networks enable achieving up to 99.999% reliability
Zero-millisecond mobility interruption time	Seamless handovers enable secure UAV operation during realization of long-distance scenarios.

Mobile networks are well suited to support low-altitude drone communication and to be integrated with drone traffic management systems to enable safe and secure drone operations. The licensed mobile spectrum serves as the foundation for mobile networks to provide wide-area, high-quality and secure connectivity enabling cost-efficient drone operations in beyond visual line-of-sight range. The potential of drone technology can be fully unleashed when both technological capabilities and regulations allow for autonomous BVLOS scenarios. Wide-area secure wireless network connectivity is required for safe expansion of drone operation range and unlocking the potential of drone technology regarding commercial applications [123].

To ensure safe operation, a reliable and secure solution for drone identification is required, i.e. drones need a tamper resistant and unique identifier that could be used for flight approvals or can be retrieved in the field allowing law enforcement to take immediate action. The identification information may include the drone owner as well as responsible pilot's specific data that could enrich the context of flight missions and in consequence ensure the establishment of responsibility and liability. The FAA's ARC committee (Aviation Rulemaking Committee) perceives cellular networks as a potential candidate to fulfil the broadcast identification and network tracking capabilities. Mobile networks can assist drones with several mechanisms which include identification, authorization or geo-fencing.

Identification and authorization of the users willing to access the network is achieved by several methods which include usage of:

- the International Mobile Equipment Identity (IMEI) which is used to identify mobile device and restricting network access for e.g. stolen devices
- International Mobile Subscriber Identity (IMSI) which is used to identify the user in a mobile network.

Apart from drones' identification and authorization, their positions over time need to be monitored to ensure air traffic safety. Up-to-date information about the locations of individual drones and the ability to locate any drone in the airspace is essential for drone traffic management system's operation. An important component of drone tracking solutions is the use of GNSS systems. Drones can retrieve their positional information and transmit it to the central server of traffic management system. The main drawback of this self-reporting solution is the risk of alteration of the telemetry data by the malicious users. In such case, fraud detection can be unachievable.

Additionally, mobile systems provide an independent location tracking mechanism that can be used to validate drones' self-reported location information. The cellular mobile positioning system (MPS) can provide a location estimate with accuracy of tens of meters which is satisfactory in terms of the telemetry data validation. In addition, the MPS positioning information can also be used as a substitutionary technology in case of malfunction of primary positioning system. In this case, MPS positioning information may be used to continue monitoring no-flight zone violations, or even detect potential incidents such as e.g. crash landings, along with an approximate position of the incident [123].

5G network can also contribute significantly to UAV communication in terms of transmission link throughput and latency. Two main transmission types can be utilized for UAVs: eMBB and uRLLC [134]. The first type is perfectly suited for links where high transmission speed is required. Typically, eMBB link can be used for high quality video streaming (4K, 8K) which is a popular drone-related service (4K FPV on board of drone, 360° VR camera view). High quality video streaming can be also utilized in several scenarios related to public safety i.e. surveillance or object recognition. uRLLC type enables achieving very low latency (1 ms) and high reliability (up to 99,999%) which can be used in time-critical scenarios. In terms of UAVs, URRLC is perfectly suited for support of C2 communication link.

Other significant functionalities that can be provided by the 5G mobile network are the mechanisms and capabilities offered by MEC [187]. The main advantages of using edge-deployed network include latency reduction, ability to deploy specific applications (video caching, AI-driven mechanisms for video analysis etc.) close to RAN as well as mechanisms facilitating handovers that can enable near to zero mobility interruption time [188]. The latter include e.g. AI-based UE's movement prediction or duplication of specific service-related functions in the UAV's vicinity, which enable network preparation for handover with timing advance and thus offer stable service continuity in high-mobility scenarios.

Using unlicensed bands shared by various types of applications would not be appropriate for some professional UAS due to risk of interference and resulting unpredictability of the used radio channels. Lack of guaranteed reliability of transmission channels as well as emission limits do not support the intended operating range may discourage potential, professional UAS service providers from investments in the field (unsecure investments). A possible solution for small-size professional UAS would be if both the command and control as well as the payload (usually video) could be transmitted within the same frequency band. It is essential due to physical capabilities of drones i.a. limited carrying capacity and battery life. In consequence, installing multiple radio units on a UAS might significantly limit the drone operation range making it unsuited even for short-distance scenarios.

One solution for the professional UAS applications is to use existing mobile MFCN networks to provide connectivity to UAS. For example, LTE technology can used as long as the C2 link meets the relevant aviation safety requirements in the country of concern. LTE connectivity can be realised either by an external standard compliant device attached to UAS or by implementing SIM-cards installed within UAS.

In such case, LTE connectivity could be used for handling service data stream as well as C2 function of UAS [135].

Depending on country-specific regulations, an aerial UE may need to be identified by the network in order to allow the use of LTE networks for aerial UE connectivity. Additionally, aerial connectivity might have dedicated services together with specific charging. Aerial UE identification solution can be a combination of user-based identification via subscription information and device functionality-based identification via LTE radio capability signalling. The subscription information can be signalled by the mobility management entity (MME) to the eNodeB, which can include information on user's authorization regarding aerial usage. In addition, an aerial UE can indicate its support of aerial-related functions via radio capability signalling to the eNodeB. Subscription information together with the radio capability indication from the UE can be used by the eNodeB to identify an aerial UE, and then perform the necessary control and the relevant functions [136].

LTE and 5G enables drone control beyond line of sight. The most important factor for this innovation is fact that line of sight between UAV and pilot is normally under 500 m in urban area. Such a limit does not allow many drone services to be performed at present. Lot of telecom operators over the world have launched trials in 2019-2020 where 5G network is used by UAVs. Mentioning some here: AT&T, China Unicom, KDDI, KPN, Swisscom, T-Mobile US, Verizon, Vodafone [137].

In January 2020, Vodafone Spain completed the world's first 5G (non-standalone) network-controlled, beyond visual line of sight drone flight in a real urban environment. This flight took place in Benidorm and was authorised by the Spanish Aviation Safety Agency (AESA).

Vodafone Spain demonstrated how 5G mobile network-based system can:

- Enable authorities to enforce static, temporary and dynamic no-fly zones in the sky.
- Remote control drones and live-stream footage from their cameras.
- Resolve potential conflicts through central control e.g. if a commercial drone flies on the same path as a police drone, the commercial drone can be asked to drop to a lower altitude [138].

Vodafone UK has joined a UK drone-testing consortium as network provider to develop tools and processes to enable unmanned aerial vehicles (UAVs) to fly safely in the same airspace as manned aircraft. Vodafone will provide 4G and 5G connectivity to the National Beyond Visual Line of Sight Experimentation Corridor (NBEC) consortium, which includes Cranfield University, Blue Bear Research and Thales. The NBEC flight corridor will be used to demonstrate how 4G and 5G can be used to identify and track the location of drones in real time, and ensure autonomous 'beyond visual line of sight' (BVLOS) flights are safe. Regulators will rule to ensure drones are constantly monitored when flying BVLOS, and enforce no-fly zones around sensitive buildings, including schools, hospitals, prisons, government buildings and chemical plants [140].

AT&T will explore with Uber how LTE and eventually 5G connectivity can enhance next-generation electric vertical take-off and landing vehicles (eVTOLs) and cargo drones. This multi-phase collaboration plans to bring together AT&T's outstanding 4G and industry-leading 5G expertise with Elevate, Uber's air mobility business unit, to support advanced technologies eventually enabling aerial ridesharing and cargo delivery applications. The companies aim to revolutionize short-range air travel and logistics by exploring next-generation operational systems communications networks that enhance safety and reliability [141].

In the USA Verizon believes drones present a growth opportunity for its budding 5G network and aims to be the first carrier to connect 1 million 5G drones' flights. Verizon has targeted drone connectivity since October 2016, when it first announced its intention to sell wireless data plans for the emerging technology.

A 5G network like Verizon's can boost the utility of drones in a number of ways:

- 5G will enable drones to transmit high-definition footage in real-time. 5G's millisecond latency and data speeds up to 100 times faster than 4G allows drones to transmit high-quality footage to operators on the ground. This enables drones to be used for functions like infrastructure safety inspections, where the drone operator must be able to see patches of rust or smalls cracks, for instance.
- Drones with a 5G connection can use AI to more efficiently complete complicated tasks. The ability to quickly transmit data enables drones to be enhanced with AI and outperform drones with a 4G connection. For example, a drone with computer vision can rapidly scan items in a warehouse and recognize patterns, which can improve efficiency and free up human workers to do more complicated tasks.
- 5G's low latency will enable precise tracking of drone fleets. As more drones begin to fly, stricter monitoring is needed to ensure they don't drift into restricted areas or crash, causing property damage or injuries. 5G's low latency can minimize lag so operators can avoid collisions and better coordinate take-offs and landings [142].

In February 2020, Japan approved bill to help firms develop 5G and drone technologies. The bill designed to help companies develop secure 5G mobile networks and drone technologies [143].

In March 2019, China Mobile implemented the first large-scale, multi-site signal control of drones under continuous 5G coverage. This test verified that drones can be controlled by 5G radio frequency signals and fly in the sky with 5G network coverage. Statistics show that 5G has reached the same level of performance as 4G and will be able to meet more future needs for drones. Testing data showed that for flying at less than 300 meters, operators can use ground-based 5G radio frequency signals to control drones. That means networks on the ground can be used to control lower flying drones without needing to deploy an additional 5G network.

As 5G drones continue to develop, they will still need to rely on multiple key elements in addition to low-altitude 5G coverage. These elements include security platforms, operating platforms and terminal modules [144].

China Mobile mentioned that the operating platform of 5G drones has to deliver three major functions: traditional air traffic control; application services for vertical industries; and value-added services for enterprise customers and consumers, such as e-commerce platforms and training and certification [144].

In August 2019, China Unicom completed a low-altitude, beyond-line-of-sight and high-speed flight test for 5G industrial drones for commercial use on Chongming Island, east China’s Shanghai [145].

4.4 5G Transmission between UAV and Ground Control Station (GCS)

DJI (Shenzhen DJI Sciences and Technologies Ltd) has drone manufacturing market share approximately 70-76% [146]. DJI is a leading brand of consumer and commercial grade drones in the world. They elaborated several solutions for transmission of the signals between the drone and Ground Control Station, for transmission of the C2 and video signals. The major differentiator between these systems is the range, the others are frequency band and video resolution.

Three basic transmission modes are used in the DJI products: WiFi, Lightbridge and OcuSync. Table 13 shows the main characteristics of the different transmission systems, which can be generally named Radio Control (RC) systems.

Table 13 Data transmission modes of DJI commercial drones

Mode	Frequency band	Models	Maximum range with LOS [m]	Video resolution Live view	Encryption
WiFi	2.4 or 5.8 GHz	Spark	500	720p HD Ready	WPA2-PSK
Enhanced WiFi		Mavic Air	2000		
Lightbridge	2.4 or 5.8 GHz	Phantom 4 Pro	3500	720p @ 30fps	
Lightbridge 2	2.4 or 5.8 GHz	Inspire 2 Matrice 600	3500	1080p Full HD	
OcuSync	2.4 GHz	Mavic Pro	4000	720p or 1080p @30fps	WPA2-PSK AES-256
OcuSync 2.0	2.4 or 5.8 GHz	Phantom 4 Pro V2.0 Mavic-2 Matrice 200 serie Matrice 300RTK	8000	1080p	WPA2-PSK AES-256

Despite of better camera resolution and possibility to record 4K or even 8K videos with very high frame rates, even the most advanced models send the live video stream to the GCS with maximum Full HD resolution only.

The maximum range of remote controlling is different for various modes, and probably it can be only achieved in the low interference conditions, what is not likely in the urban areas. The OcuSync is said to be less susceptible to the radio interferences, even in the presence of other strong radio signals. If buildings are located between line of sight between pilot and drone the maximum range of remote controller of DJI Matrice, Inspire, Phantom or Mavic drones is approximately 500 m [147].

5G and earlier packet transmission-centric cellular networks have many advantages over the traditional methods of controlling the UAV with Radio Communication (RC) narrowband or wideband link. Table 14 shows the advantages of 5G technology over the legacy RC technologies per subject.

Table 14 Advantages of 5G technology over the legacy RC technologies

Legacy RC	5G	5G!Drones Use Cases (UC) pertinence
Pilot/GCS presence close to the flight area		
Required – the Ground Control Station (GCS) must be close to the UAV to assure connectivity.	Not required – GCS can be remote or in MEC to assure low latency.	Remote control and GCS in MEC are planned for all UC.
First Person View support		
Possible, up to Full HD resolution.	Provided with separate isolated slices having specific QoS. Resolution beyond Full HD possible.	Vital feature for direct stick steering BVLOS scenarios.
Impact of radio interferences - dedicated, licensed band usage		
The legacy solutions usually work in ISM bands, used simultaneously by many	5G networks will use dedicated licensed bands and features enhancing interference management.	Common for all UC, increasing the security and reliability of C2 link.

Legacy RC	5G	5G!Drones Use Cases (UC) pertinence
different use cases, where the risk of interference or jamming is high. Especially, in areas with high drone traffic density such operation will be impossible.		
Omnipresence of the service		
Not feasible – local service only. Increasing coverage requires deploying a large number of dedicated gateways, which is feasible but not cost-efficient at large scale.	Service area is dependent on 5G coverage of the operator, which ultimately will be countrywide, or even beyond – with seamless roaming. Ad-hoc 5G coverage deployment on demand can be also imaginable if conditions are set by the regulator or met by business cases. In case the constant QoS cannot be provided everywhere, the lower level QoS (minimum) can be agreed in regions of lower network performance.	Our tests will be performed in relatively small area, limited to the test facility, but in general, the omnipresence of the service and its cost are the main drivers.
Multiple UAV handling		
Not designed for this purpose	Possible to handle huge number of UAVs in the same time and the same space. Additionally, if the 5G network-based connectivity is treated as one of U-space resources (similarly to e.g. airspace), the efficient U-space resources management can be targeted to optimize the flight planning process due to active rearrangement of demands to accommodate as many flights as possible in order to maximize the approval ratio and balance the average utilization of U-space resources.	Important in majority of the UC. In many UC UAVs collaborate to complete the mission.
Quality of Service (QoS)		
Not assured	Standardized, can be guaranteed with SLA associated to slices. QoS may be differentiated depending on the location. 3D QoS-indicating coverage estimation data may be shared by the Network Operator with U-space Provider.	QoS is assured in all UC on the slice level. Each UC will require at least 2 slices, except UC1:SC1 UTM Deployment 1, where only C2 link is required.
Mobility		
No mobility	Handovers and mobility are part of the standard.	All scenarios will be tested in one gNB configuration. However, for long distance flights or flights in dense urban areas the mobility management feature is vital.

Legacy RC	5G	5G!Drones Use Cases (UC) pertinence
Service recovery mechanisms		
Basic – return to the point where signal was better	Highly sophisticated – on the different protocol layers, with dedicated features (i.e. RRC Connection Reestablishment), using intra- and inter-technology mobility, data retransmission, buffering etc.	We do not plan to use inter-technology mobility during our tests. Other features (depending on the deployed 3GPP release and implementation status) will be used.
Immediate access to the payload		
Yes, with wideband RC link. Otherwise the payload is accessible after finishing the mission.	Yes, with different QoS, specified on the slice level and in accordance to SLA.	Basic requirement for all UC.
Tracking of UAV		
Based on info received by RC link	5G System can support and use Location Services (LCS) for locating UAV independently of its GNSS system. However, the non-UE-based, Network-Assisted Location mode needs implementation of LCS support in gNBs.	We have UC3:SC2 “Location of UE in non-GPS environments”, but it will not use LCS service offered by cellular NW, but inputs from multiple sensors on board of UAV including different 5G signal-related parameters.
Modulation and Coding Scheme (MCS) adaptation and scheduling of the data performed in Packet Scheduler (PS)		
Basic	Sophisticated – data stream type-dependent.	Packet Scheduler (PS) and MCS are basic cellular NW functions. Used for all UC.
Support of distributed data processing architectures		
No	With selective User Plane traffic routing and implementation of Edge Computing/MEC both C2 and payload stream can be processed (enriched, augmented, transcoded, aggregated etc.) in transit to optimize data transmission, volume, latency etc.	Will be used for all UCs.
Increased UAV autonomy and operation time thanks to shift of computing power, to Edge or MEC		
No	With MEC or similar solutions, transcoding or other data processing offloading is possible.	Will be used for selected UCs.

Legacy RC	5G	5G!Drones Use Cases (UC) pertinence
Connectivity to U-space		
No, unless using cellular network to connect GCS to U-space.	Yes, the 5GS can expose Control Plane services to other system. In case of the User Plane traffic, the additional security level can be offered (5G operator can be Trusted 3rd Party, testifying integrity of information sent from/to the U-space).	Integration of 5G!Drones Trial Engine with U-space is very important and will serve for all UCs.
Open market		
Single standard not existing.	Worldwide standard, accessible for everybody.	
Identity handling and privacy		
UAV specific identities can be locally used, if UAV has them.	Telecom identities: IMEI and IMSI can be used in parallel with other UAV-specific IDs. They all can be communicated to centralised e-registers, the 5G network can certify them, and privacy is kept to the highest degree.	External e-Registers from government agencies are planned to be used for all UC. As they are not in place yet, it's hard to say which IDs types will be utilised.
Controlled mobility for best connectivity		
Basic. This is challenging, because of variability of signal in ISM bands.	The connectivity can be improved if UAV location or possibly the flight plan can be adapted, thanks to 5G radio propagation models.	Drone for UC1:SC2 3D mapping, UC2:SC2 Disaster recovery, and UC4:SC1 Connectivity may demonstrate the impact of UAV location for improving QoS

The result of this comparison is clear – the cellular networks and particularly 5G with its new promising features, are very well suited to serve the drone industry requirements in multiple aspects. uRLLC is the key for U-space services, especially ultra-reliance. Other 5G technologies to be exploited would be positioning services as a backup for GNSS, and services to analyse population in real time (to manage ground risks in SORA). Another important service is the 4D (3 spatial dimensions and time) mobile network coverage mapping services.

4.5 Benefits of 5G Technology for 5G!Drones Use Cases

Based on the scenarios carried out during the project and fully detailed in deliverable D1.1, the following benefits of 5G technology can be highlighted.

4.5.1 UC1:SC1 – UTM command and control application

This scenario utilizes a whole range of 5G functionalities. The most important are:

- No need of physical GCS in the location of the drone flight – in our scenario it is replaced by virtual controller running in the MEC. It can be virtually anywhere in the Internet, but due to the latency requirements, it will be placed somewhere in the IT infrastructure of Network Operator.
- The range of the mission is not limited to the range of the RC controller. Thanks to the mobile network coverage, it's much larger.
- Before take-off the UAV can be verified and authenticated with the identities, which are used in telecom networks, like IMSI and IMEI. This gives very little room for malicious use and spoofing.
- C2 link and First Person View video links are carried by two independent network slices with different QoS, different transmission error protection, created and managed separately. In case of problems (interferences, lack of capacity, other requests with higher priority), the C2 link will be maintained, whilst the other is dropped.
- Thanks to 5G connection, U-space has a full situational awareness what is happening with the UAV and can intervene in case of emergency
- 5G MEC-based UTM system for managing airspace in near real time and to support collision avoidance solutions.
- 5G's low latency will enable precise tracking of drone fleets by UTM systems. As more drones begin to fly, stricter monitoring is needed to ensure they don't drift into restricted areas or crash, causing property damage or injuries. 5G's low latency can minimize lag so operators can avoid collisions and better coordinate take-offs and landings.

4.5.2 UC1:SC2 3D mapping

The UC1:SC2 is expected to use the existing 5G capability of the Oulu 5GTN for its deployment. In this scenario, a set of new technologies are used to visualize the real time operation of drone fleets. Using VR as a visualization platform, multiple source and huge amount of data can be expressed in visual format that is easier for human operators to understand. This use case studies the possibilities of using VR for drone operation and real time visualization.

For faster application process at the edge, different MEC slices will be dedicated for various application processing before being transmitted back to the operation centre. Even though not all measurements or applications will be processed at the MEC, services such as video processing, 3D map analysis, sensors measurement processing will be done at different MEC slices before further transmission to the operating centre.

4.5.3 UC1:SC3 – UAV logistics

In this scenario, Drone Logistics Network Delivery Software (DLN DS) coordinates delivery information between customer delivery box, UAV and logistics centre.

5G communication allows the use of high-quality video transmission to Control Rooms to enable situational awareness (eMBB) and use remote control using uRLLC in near real time.

If drone has bad GPS signal conditions then low latency is very important for controlling drones remotely by Control Room operators (uRLLC).

4.5.4 UC2:SC1 – Monitoring a wildfire

For the Rescue, 5G communication allows the use of high-quality video transmission to Control Rooms and use video analytics servers in near real time (eMBB) on 5G MEC. Because Rescue officers do not usually have time to deal with drone control on the site of accident, low latency is very important for drones to control remotely by Control Room officers (uRLLC).

UAV video stream over 5G allows public safety users to access near real-time high-quality video stream and near real time analytics. First responders can use 5G smartphones to watch high quality video stream and data from UAVs and from IoT cameras.

4.5.5 UC2:SC2 – Disaster recovery

Public protection and disaster relief (PPDR) has been identified a potential vertical where the use of drones will have a major impact. Drones have already been used in the US to assist emergency services as well as businesses in the aftermath of hurricanes. Typical use cases include providing on-demand connectivity for affected citizens [150], surveying damages on public infrastructure as well as residential and commercial properties [151].

Within the context of the Disaster Recovery use case, the goal is to deploy, control and manage a swarm of drones autonomously through Unmanned Life's Autonomy-as-a-Service software platform using 5G connectivity. Each drone will possess a different capability ranging from real-time video streaming to providing on-demand connectivity. Moreover, Unmanned Life's software platform deployed on the edge will also be responsible for conducting AI-assisted object recognition.

To enable the above features within this use case in a commercial environment, the following major 5G functionalities will be utilized:

- Unmanned Life's GCS (UL-CCP) used to remotely control the drones will run on the edge infrastructure of the 5G network provider. This will enable the drone to offload much of its processing requirements to the edge, enabling real-time analysis of sensor data that would be difficult or unfeasible to run directly on the low-powered computational devices carried by the UAV, supporting the proliferation of low-cost UAVs while still enabling high-level autonomous behaviour
- The eMBB slicing features of 5G will enable high-quality videos to be streamed in real-time to the edge for conducting AI-assisted analysis. Moreover, the uRLLC slice will enable UAV operator's to control and manage bigger swarms of autonomous drones.
- Once deployed on a wider scale, the omnipresence of 5G connectivity as well as availability of MEC will allow the drones to cover a greater area through successful handovers conducted between 5G towers. This will also enable the network operator to provide an assured QoS to its UAV operator customers.
- With widespread deployment of 5G connectivity, the various aspects of U-space services such as UTM, ATM, and drone services can be tightly integrated ensuring a near constant visibility thus maintaining security and safety in the skies.
- Finally, flight plans can be altered in real-time if 5G radio propagation models are made available in the future.

While the scope of the trials within 5G!Drones maybe restricted due to technology limitations, these trials will lay the foundation for business cases requiring tight integration of UTM, UAV, and network services. As increasingly advanced services become available in the future, they can be integrated into a pre-existing business framework. This promotes a smooth transition to higher levels of UAV autonomy in day-to-day operations.

4.5.6 UC2:SC3 – Police

When Police uses UAVs, the 5G communications channel is important in solving time-critical tasks with high-volume data flow. Police needs slicing for secured communication and running restricted applications. For the police, 5G communication allows the use of high-quality video transmission to Control Rooms (eMBB) and use analytics servers in the near real time (MEC). Because Police officers do not usually have time to control a drone on the site, low latency is very important for drones to be controlled remotely by Control Room officers (using advantages of uRLLC).

In all of these applications, the connectivity of the drone with the ground station, and other data platforms is of high importance. Having a 5G network will not only enable BVLOS operations, it would also enable the operation of large fleets of drones in the airspace without having to worry about the bandwidth being affected.

4.5.7 UC3:SC1: Sub-SC1 – 3D Mapping of 5G QoS

The use case shall leverage the 5G experimentation capabilities of 5GTN. This will require a network infrastructure that will provide 2 network slices:

1. Drone C2.
2. 5G signal measuring results real time transfer.

This scenario involves monitoring real time quality of signal; hence it needs a dedicated uRLLC slice. It also involves the C2 data transmission.

For 3D measuring there are 2 critical elements:

1. Accurate real time positioning.
2. Same timestamps for measuring and drone positions data.

The data processing will be achieved at the edge using MEC capabilities. To achieve this trial, a network infrastructure that supports the necessary slices and functionalities in this use case is required. The Oulu 5GTN will provide a dedicated MEC server for process this data.

4.5.8 UC3:SC1: Sub-SC2 – Long range power line inspection

Using 5G for infrastructure inspection enables to move towards real-time defect detection and analysis as the information gathered from the drones can be processed while performing the flight. As more efficient inspection service requires more use of artificial intelligence on-board the drone to perform automatic data gathering, processing and defect detection which in turn increases the cost and weight of the aircraft then by using the 5G technology it is possible to move the resource-heavy computation away from the aircraft. This method increases the flexibility of inspection by drones as the aircraft itself does not have to contain the entire necessary infrastructure for resource-hungry computation. That means that depending on the need or location of the inspection drones with different sizes can be used. Based on our experience first implementation of 5G network still needs to use human interaction for performing the real-time defect detection as the information can be sent to the operator with a very low latency. The operator can then take action to modify drone's flight plan to get a better understanding of the defect. One of the key factors where 5G and cloud computing can be especially useful is to perform traffic and obstacle avoidance tasks as the avoidance plan can be worked out using cloud computing and necessary actions can be sent to the drones.

Later implementation would also benefit from automatic defect detection as the faults will be processed and analysed in the cloud and if defects are found, then necessary actions can be taken. This will also make it possible to forward the results of the inspection to the interested parties while the flight is on-going.

4.5.9 UC3:SC1: Sub-SC3 – Inspection and SAR operations in large body of water.

The goal of the operation is to monitor the state and the evolution of water bodies such as rivers, streams and lakes. For this purpose, a hybrid drone equipped with the required sensors (water quality probes, sonar/LIDAR…) patrols or is sent on the water and gathers data. This data is then post processed to produce a report on the water quality and a map of underwater depth (bathymetry).

Some requirements in terms of performance and QoS must be considered in order to carry out our scenario appropriately. The following 5G services will be helpful in order to accomplish a set of objectives:

- uRLLC 5G service will provide low latency for telemetry data streamed to the GCS to ensure a very fast, near real-time two-way communication between drone and GCS.
- eMBB 5G service will be useful for first-person view camera data (BVLOS operations) as well as sensor data for 3D depth map reconstruction and other sensor data from UAV to Alerion processing application running at the Edge.

4.5.10 UC3:SC2 – UAV-based IoT data collection

5G will play a key role in enabling the scenario "UAV-based IoT data collection". First of all, the consideration of such mobile networks will allow flying the drones far from the control centre to collected IoT data from locations which cannot be reached using direct radio links. Cellular networks are known for being massively deployed, enabling therefore remote sensing and BVLOS applications. Moreover, 5G is foreseen as the communication standard to accommodate densely devices. UAV-based IoT data collection is one the beneficiary applications as the number of deployed IoT is growing rapidly on the ground but also in the sky. Furthermore, unlike 'one-size-fits-all' architecture, 5G can support different services requirements. While the control of the flying UAVs requires reliable and low-latency communication (which is due to the critical nature associated to drone applications), the data generated by the IoT devices can be huge and put a huge pressure on the network. This reflects two conflicting services which can be not supported by legacy networks.

IoT sensor based on 5G NB-IoT or LTE-M Cat1/2 technology allows reliable communication between delivery box IoT Sensors and drones and Control Rooms.

4.5.11 UC3:SC3 – Location of UE in non-GPS environments

5G provides LMF (Location Management Function), where the position information of the flying UAV(s) can be received. As this information is get from CSP (Communication Service Provider) and this secondary positioning source is CSPs NG RANs, LMF gives an option to compare position information coming from different sources and detect, if UAV's telemetry SW or HW is altered and give an option to alarm if there is invalid position information feed to the UTM system and the ground control system.

5G eMBB feature connected to nearby MEC solutions gives an possibility to receive and process in real time data from multiple sensors like LIDAR, camera etc. on board of UAV including different 5G signal-related parameters, so UAV position can be calculated accurately.

4.5.12 UC4:SC1 – Connectivity extension and offloading

5G technology shall be exploited to ensure connectivity for a crowded event through the ad-hoc deployment of a lightweight drone on-boarded base station. To support extended connectivity, QoS and 3D Mapping solutions for network planning during crowded events is important as it enables reduction of deployment times compared to current (ground-based) solutions.

5G will enable drones to transmit high-definition footage in real-time. 5G's millisecond latency and data speeds up to 100 times faster than 4G allows drones to transmit high-quality footage to operators on the ground. This enables drones to be used for functions like infrastructure safety inspections, where the drone operator must be able to see patches of rust or smalls cracks, for instance. Receiving this high-quality footage in real-time allows operators to make adjustments during the flight (e.g., to perform a closer inspection of a suspected fault during a safety inspection), rather than necessitating additional flights after offline review of the footage.

5G's low latency will enable precise tracking of drone fleets by UTM systems. As more drones begin to fly, stricter monitoring is needed to ensure they don't drift into restricted areas or crash, causing property damage or injuries. 5G's low latency can minimize lag so operators can avoid collisions and better coordinate take-offs and landings.

Drones with a 5G connection can offload resource demanding tasks at the edge of the network (e.g. AI-related tasks), allowing them to efficiently perform and complete more complicated tasks. For

example, a drone with computer vision can rapidly scan items and recognize patterns, which can improve efficiency and free up human workers to do more complicated tasks. Offloading computationally expensive (and latency-sensitive) tasks to the edge of the network can provide drones with higher-level functionality without the additional power and weight burden of the required computational components. This benefits drones both in improving their flight times and in reducing their individual cost.

5 CONCLUSION

In this document, conducted as part of the 5G!Drones project, the relevant UAV market and regulation analysis is presented covering both commercial (private businesses) and governmental (public authorities) UAV services, while military drones are considered out of the project's scope.

As presented in Section 2, enterprise drones are defined as all unmanned aerial vehicles (UAVs) sold directly to a business for use in its operations. Under that criterion, Business Insider Intelligence predicts total global shipments to reach 2.4 million drones in 2023. FAA projected that the non-model commercial sUAS sector in the USA will have over 835,000 aircrafts in 2023. SESAR JU predicted 830,000 commercial UAVs in Europe by 2030. Although analysis of the market of UAV services and forecasts for the sale of drones and drone services have started to become more harmonized since 2020, the differences from the forecasts are still in the margin of 30%-50%. As the market of drone services begins to mature, more data will emerge, allowing for more accurate analysis and forecasting. In 2018, a survey of 1,700 companies with an annual turnover of at least USD 50 million was conducted in the United States on behalf of Skyward that has revealed the following facts:

- About 10% of companies have used drones.
- About 63% of these companies develop in-house drone competence, not buying it as a service.
- 92% said their company saw a positive return on its drone investment within one year.

Predicted value by drone related services industry globally in 2030 shows that four main sectors, Infrastructure and Construction; Agriculture; Logistics; Air Taxis account for about 70% of the total drone services. As the total value of drone services market will be 150 billion USD, the document in Section 2 proceeds to report specifically on these areas. In the public sector area, our study analyses further the Police, Rescue and Drones to prevent pandemics cases. Since February 2020, drones have been radically used in Spain, France, China, USA to fight against the spread of COVID-19, a coronavirus pandemic that has broadened societies' awareness of the potential of drones and contributed to innovation of drone services.

A thorough analysis in respect to regulation, current (national) and under formation (EU) legislation in terms of UAV flight permits, and 5G spectrum allocation is presented in Section 3 with specific focus on the countries that the project plans demonstration flights (Finland, France and Greece). It must be noted that currently it's not allowed to use modems and mobile phones on board a UAV in Finland -mainly due to unsolved interference issues - and similar restrictions exist in France. Nonetheless, a permission to use UAV with attached 5G device can be applied via the national Radio Communication Agency. From 01.07.2020, national UAV flights rules will be gradually replaced by a common EU regulation (Commission Delegated Regulation (EU) 2019/945 and Commission Implementing Regulation (EU) 2019/947 and Commission Implementing Regulation (EU) 2020/639. The purpose of this reform is to create a truly harmonised drone market in Europe with the highest level of safety.

The 5G network technology is expected to contribute significantly to UAVs communication in terms of transmission link throughput (through the eMBB service) and latency (through the uRLLC service). Other 5G technologies to be exploited would be positioning services as a backup for GNSS, and identification and 5G MEC-based applications. These are presented in Section 4, together with an extensive report on the standardisation activities and on-going work of the 3GPP Working Groups to ensure that the 5G system will meet the connectivity needs of Unmanned Aerial Systems (UAS). Specific analysis of the specific impact of 5G technology on the 5G!Drones target use cases concludes this part of the document.

As 5G use cases have evolved, new studies and new features are needed, for the safe operation of UAVs, but also to ensure that other users of the network do not experience a loss of service due to their proximity to Unmanned Aerial Systems.

As a key conclusion six factors are highly-critical for the development of UAV services:

- Regulation that supports BVLOS and automated flights of UAVs.
- Regulation in the field of radio communication, which supports the use of 5G devices on board UAVs.
- Building of a radio networks by telecom operators to support the operation of UAVs.
- Integrate or add 5G or other devices into UAV by the drone manufacturer and allow the use of MFCN services.
- Companies whose business benefits from the use of UAVs.
- Standardization of 5G technology to support UAV related services.

In the forthcoming deliverable (D1.7) that is planned at the end of the project in May 2022, the framework of analysis will be updated and further enriched, taking into consideration all the project developments, achievements and results along with the prevailing market, business, regulatory and 5G advances during the next phases of the project. 5G!Drones trials, their results and rest project achievements will be fully investigated to form the foundations for a novel UAV operations framework within a niche business, market and regulatory environment, where 5G UAV cases will be available, new business models will be introduced and new regulations will apply and guide UAV business and market related activities.

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7 ANNEXES

7.1 Annex 1 – FR1 Operating Bands and Channel Bandwidths [167]

NR band	UL operating band (MHz)	DL operating band (MHz)	Duplex mode	Channel bandwidths (MHz)
n1	1920-1980	2110-2170	FDD	5, 10, 15, 20
n2	1850-1910	1930-1990	FDD	5, 10, 15, 20
n3	1710-1785	1805-1880	FDD	5, 10, 15, 20, 25, 30
n5	824-849	869-894	FDD	5, 10, 15, 20
n7	2500-2570	2620-2690	FDD	5, 10, 15, 20, 25, 30, 40, 50
n8	880-915	925-960	FDD	5, 10, 15, 20
n12	699-716	729-746	FDD	5, 10, 15
n14	788-798	758-768	FDD	5, 10
n18	815-830	860-875	FDD	5, 10, 15
n20	832-862	791-821	FDD	5, 10, 15, 20
n25	1850-1915	1930-1995	FDD	5, 10, 15, 20
n28	703-748	758-803	FDD	5, 10, 15, 20
n29	N/A	717-728	SDL	5, 10
n30	2305-2315	2350-2360	FDD	5, 10
n34	2010-2025	2010-2025	TDD	5, 10, 15
n38	2570-2620	2570-2620	TDD	5, 10, 15, 20
n39	1880-1920	1880-1920	TDD	5, 10, 15, 20, 25, 30, 40
n40	2300-2400	2300-2400	TDD	5, 10, 15, 20, 25, 30, 40, 50, 60, 80
n41	2496-2690	2496-2690	TDD	10, 15, 20, 30, 40, 50, 60, 80, 90, 100
n48	3550-3700	3550-3700	TDD	5, 10, 15, 20, 40, 50, 60, 80, 90, 100
n50	1432-1517	1432-1517	TDD	5, 10, 15, 20, 30, 40, 50, 60, 80
n51	1427-1432	1427-1432	TDD	5
n65	1920-2010	2110-2200	FDD	5, 10, 15, 20
n66	1710-1780	2110-2200	FDD	5, 10, 15, 20, 40
n70	1695-1710	1995-2020	FDD	5, 10, 15, 20, 25
n71	663-698	617-652	FDD	5, 10, 15, 20
n74	1427-1470	1475-1518	FDD	5, 10, 15, 20
n75	N/A	1432-1517	SDL	5, 10, 15, 20
n76	N/A	1427-1432	SDL	5
n77	3300-4200	3300-4200	TDD	10, 15, 20, 40, 50, 60, 80, 90, 100
n78	3300-3800	3300-3800	TDD	10, 15, 20, 40, 50, 60, 80, 90, 100
n79	4400-5000	4400-5000	TDD	40, 50, 60, 80, 100

NR band	UL operating band (MHz)	DL operating band (MHz)	Duplex mode	Channel bandwidths (MHz)
n80	1710-1785	N/A	SUL	5, 10, 15, 20, 25, 30
n81	880-915	N/A	SUL	5, 10, 15, 20
n82	832-862	N/A	SUL	5, 10, 15, 20
n83	703-748	N/A	SUL	5, 10, 15, 20
n84	1920-1980	N/A	SUL	5, 10, 15, 20
n86	1710-1780	N/A	SUL	5, 10, 15, 20, 40
n89	824-849	N/A	SUL	5, 10, 15, 20
[n90]	2496-2690	2496-2690	TDD	10, 15, 20, 30, 40, 50, 60, 80, 90, 100

7.2 Annex 2 – FR2 Operating Bands and Channel Bandwidth [169]

NR band	UL operating band (MHz)	DL operating band (MHz)	Duplex Mode	Channel bandwidths (MHz)
n257	26500-29500	26500-29500	TDD	50, 100, 200, 400
n258	24250-27500	24250-27500	TDD	50, 100, 200, 400
n260	37000-40000	37000-40000	TDD	50, 100, 200, 400
n261	27500-28350	27500-28350	TDD	50, 100, 200, 400