"5G for Drone-based Vertical Applications"

D1.7 Final report on UAV business and regulatory ecosystem and the role of 5G

Document ID:	**D1.7**
Deliverable Title:	**Final report on UAV business and regulatory ecosystem and the role of 5G**
Responsible Beneficiary:	**INF**

Topic:	**H2020-ICT-2018-2020/H2020-ICT-2018-3**
Project Title:	**Unmanned Aerial Vehicle Vertical Applications' Trials Leveraging Advanced 5G Facilities**
Project Number:	**857031**
Project Acronym:	**5G!Drones**
Project Start Date:	**June 1st, 2019**
Project Duration:	**42 Months**
Contractual Delivery Date:	**M42**
Actual Delivery Date:	**November 28th, 2022**
Dissemination Level:	**Public (PU)**
Contributing Beneficiaries:	**INF, THA, ALE, INV, NCSRD, AU, COS, NOK, RXB, EUR, CAF, FRQ, OPL, UMS, DRR, UO**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857031.

Document ID:	D1.7
Version:	v1.0
Version Date:	25 November 2022
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Security:	Public (PU)

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Document History

Version	Contribution	Authors	Date
0.1	Initial version, ToC	INF	07/02/2022
0.2	Contributions in Sections 1.1, 2.1, 2.2, 2.2.1.1, 2.2.1.2	INF	01/03/2022-23/05/2022
0.3	Contributions in Sections 1.1, 2.1, 2.2, 2.2.1.1, 2.2.1.2, 2.2.1.3, 2.2.1.4, 2.2.2.1, 3.2.1, 3.2.3, 4.2.1, 4.4.1	UO, NCSRD, INV, OPL, COS, ALE, INF	01/06/2022
0.4	Contributions in Sections 2.2.2, 2.2.2.1. 2.2.2.2, 4.3, 4.4	INF, NCSRD, INV	18/7/2022

0.5	Contributions in Sections 2.1, 2.2, 2.2.3, 3.1, 3.1.1, 3.2.1, 3.2.2, 4.2, 4.2.2	INF, RXB, UML, FRQ, COS, NCSRD, OPL	21/09/2022
0.6	Contributions in all sections	INF, NCSRD, AU, THA, NOK, UML	03/10/2022
0.7	Contributions in all sections	All Partners	17/10/2022
0.8	Contributions in all sections	All Partners	31/10/2022
0.9	Final contributions in all sections	All Partners	08/11/2022
0.91	Final editing – internal review version	INF	13/11/2022
0.95	Final version for TM, PMT, PC check	INF	21/11/2022
1.0	Final version	INF	25/11/2022

Executive Summary

Within the continuous evolving 5G-UAVs environment, this deliverable, as an updated version of its previous release (D1.4), provides an update on the analysis of the current state of the overall UAV market, the corresponding regulatory environment, with a particular focus on the role of 5G technology and how through 5G!Drones it can affect the UAVs market and business environment with recommendations and new propositions as a result of the outcomes of the 5G!Drones use cases and trials.

In specific, an updated analysis of the current UAV market/business areas with focus on UAV markets and services related to commercial, and non-commercial (governmental) sectors, as they have been further evolved during the period 2020-2022, is presented. This market analysis also links the market characteristics of the 5G!Drones project four use cases with the characteristics and trends of new emerging markets and business processes, originating by UAV evolution, sufficient regulatory framework, 5G advent and 5G-UAVs coupling.

In parallel, the regulation framework's analysis puts special emphasis on latest EU regulation updates (EU legal framework changes in 2021 for facilitating and securing UAVs commercial and non-commercial use) and the three countries where 5G!Drones trials were conducted (Finland, France, and Greece), setting the formal requirements in which UAV markets operate. An overview of the US regulation is also considered in relation to the corresponding EU one.

The 5G technology, market and business impact in 5G!Drones use cases and in UAVs overall is also considered. A brief technical overview of the 5G!Drones four 5G experimental platforms as well as their performance results along with a business impact analysis to 5G!Drones UC areas is analysed, as perceived by the different stakeholders' perspective within 5G!Drones consortium.

Based on the findings and expertise gained for 3.5 years within 5G!Drones project and executed UCs by the consortium, the 5G!Drones conclusions are presented, elaborating on how can 5G and UAVs be effectively combined, addressing new markets, products, and services. Perspectives, lessons learned, recommendations and future pathways are also presented from UAV, 5G and consortium point of view.

Finally, further potential research opportunities are identified and presented.

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List of Abbreviations

3GPP	3rd Generation Partnership Project
5G CPE	5G Customer Premise Equipment
5G-NSA	5G Non-Standalone
5G-PPP	5G Infrastructure Public Private Partnership
5GS	5G system
5G-SA	5G Standalone
A2G	Air to Ground
AAM	Advanced Air Mobility
AGL	Above the ground
AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
API	Application Programming Interface
ARC	Air Risk Class
ARCEP	Autorité de Régulation des Communications Électroniques, des Postes et de la distribution de la presse
ATC	Air Traffic Control
ATM	Air Traffic Management
B5G	Beyond 5G
BS	Base Station
BVLOS	Beyond Visual Line of Sight
C2	Command-and-Control
CAGR	Compound Annual Growth Rate
CEO	Chief Executive Officer
CONOPS	CONcept of OPerationS
COVID-19	COronaVIrus Disease of 2019
D2D	Device to Device
DN	Data Network
DGAC	Direction Générale de l'Aviation Civile
DoF	Degree of Freedom
DSAC	Direction de la Sécurité de l'Aviation Civile
Dx.y	Deliverable No y of Work Package x
E2E	End to End
EANS	Estonian Air Navigation Services
EASA	European Aviation Safety Agency
eMBB	Enhanced mobile broadband
EU	European Union
EVLOS	Extended Visual Line of Sight
eVTOL	Electric Vertical Take-off and Landing
FAA	Federal Aviation Administration
FOCA	Federal Office of Civil Aviation
FRIA	FAA-recognised identification areas
GAPR	Compound annual Growth Rate
GBS	Ground Base Station
GCS	Ground Control Station
gNB	Next Generation Node B
GPS	Global Positioning System
GRC	Ground Risk Class
HCAA	Hellenic Civil Aviation Authority

ICAO	International Civil Aviation Organization
IOSO	Identification of the Operational Safety Objectives
IoT	Internet of Things
IoUAV	Internet of UAV
IPP	Integration Pilot Program
JCAS	joint communication and sensing
LAANC	Low Altitude Authorization and Notification Capability
LBO	Local Break-Out
LCM	Life Cycle Manager
LiDAR	Light Detection and Ranging
LoS	Line of Sight
LTE	Long Term Evolution
LUC	UAS operator certificate
MEC	Multi-access Edge Computing
MIMO	Multiple Input, Multiple Output
mMTC	Massive machine-type communications
MNO	Mobile Network Operators
MTOW	Maximum Takeoff Weight
NAA	National Aviation Authorities
NASA	National Aeronautics and Space Administration
NB-IoT	NarrowBand-Internet of Things
NDVI	Normalised Difference Vegetation Index
NF	Network Function
NR	New Radio
NRA	National Regulation Authority
NTN	NonTerrestrial Networks
OAI	Open Air Interface
OPEX	Operational Expenditure
O-RAN	Open Radio Access Network
OSO	Operational Safety Objectives
PDRA	Pre-Defined Risk Assessment
PE	Private Equity
PLMN	Public Land Mobile Network
RAN	Radio Access Network
RGB	Red Green and Blue
QoS	Quality of Service
OSM	Open Source Mano
QR	Quick Response code
RPAS	Remotely Piloted Aircraft Systems
SAIL	Specific Assurance and Integrity Level
SAR	Search and Rescue
SDN	Software Data Network
SDO	Standards Developing Organization
SME	Small Medium Enterprises
SORA	Specific Operations Risk Assessment
TMPR	Tactical Mitigation Performance Requirements
U-space	Unmanned Airspace
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UAVBS	UAV as flying Base Station
Ux	Use Case x

UCSCx	Use Case Scenario x
UE	User Equipment
UPF	User Plane Function
URLLS	Ultra-Reliable Low Latency Communications
USSP	U-Space Service Providers
UTM	Unmanned Aviation Systems Traffic Management
VAS	Value Added Services
VLOS	Visual Line Of Site
vMEC	virtual Multi-access Edge Computing
WiFi	Wireless Fidelity
WP	Work Package

1 Introduction

1.1 Objective of the Document

The main objective of this deliverable is the final presentation and analysis of the UAV market, business and regulatory ecosystem within the context of 5G and its broad applications. 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 initially an update on the analysis of the current state of the overall UAV market and the corresponding regulatory environment that is applied following a particular focus on the role of 5G technology and how through 5G!Drones it can affect the UAVs market and business environment and introduce new products and services while targeting new markets and business processes.

The undertaken analysis will identify key application areas, where 5G technology can provide new or enhanced services, and how each stakeholder in the related UAV and 5G value chain (such as UAV operators and equipment vendors, 5G and telecommunication operators/providers, academia, and research institutions), 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 has undertaken significant changes that may have impact on both how UAV vertical services should operate and how the 5G!Drones trials will be executed.

The activities of T1.1 "Analysis of the UAV business and regulatory ecosystem and the role of 5G technology and their outcomes" were initially reported in D1.4 through a high-level analysis of the current status and trends, and then they are 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 last phases of the project.

This deliverable also sums up its scope through the provision of the impact created in the business environment by the 5G!Drones use cases and the four 5G experimental platforms. 5G!Drones consortium, based on the experience and knowledge gained, makes recommendations, provides insights and future pathways for the evolution of the UVAs in the upcoming 5G business and market environments.

1.2 Structure of the Document

This deliverable is structured in five chapters, providing an updated version of the topics and content presented in D1.4 (May 2020):

- **Chapter 1** presents an introduction of the deliverable focusing on its objectives, structure, target audience, and scope.
- **Chapter 2** presents an updated analysis of the current UAV market/business areas with focus on UAV markets and services related to commercial, and non-commercial (governmental) sectors. as they have been further evolved during the period 2020-2022, where due to COVID-19, new areas of UAVs usage have been developed and presented in this document. Please note that UAVs military services/markets are considered as out of the scope of this project/deliverable In parallel, in this chapter of the document, market and business-related trends are presented per use case area.
- **Chapter 3** presents and analyses the overall updated regulatory framework (2020-2022 period), including UAV flights categories, regulations and 5G spectrum policies, and their impact on the prevailing use cases. Special focus is provided to the updated overall EU and local regulatory

framework of the three countries where the 5G!Drones trials were performed (France, Finland and Greece). In parallel, an overview of the US regulation is presented in relation to the corresponding EU.

- **Chapter 4** presents the 5G technology market and business impact in 5G!Drones Use Case (UC) markets and UAVs overall. Specifically, it initially provides a technical overview of the 5G!Drones four 5G experimental platforms as well as their performance results. A business impact analysis to 5G!Drones UC areas follows, presented as it is perceived by the different stakeholders' perspective within 5G!Drones consortium.

  Summing up this chapter, based on the findings and expertise gained for 3.5 years within 5G!Drones project and tested UCs by all partners, the 5G!Drones aspects are presented, elaborating on how can 5G and UAVs be effectively combined, addressing new markets, products and services. Perspectives, lessons learned, recommendations, and future pathways are presented from UAV, 5G and consortium point of view. Finally, potential research opportunities are considered.

- **Chapter 5** concludes this deliverable.

Please note that analysis of the 5G!Drones technical results, KPIs, trials, their evaluation and their technical impact is beyond the scope of this deliverable and are presented in D4.4

1.3 Target Audience

Similarly, to the previous edition (D1.4) of this deliverable, D1.7 is mainly addressed to:

- **The UAV industry, operators and stakeholders** who will become aware of the UAV advances and the current market, business and regulatory framework and how it can take advantage of the use of the 5G technology (already in intense deployment worldwide by major telco operators).
- **5G providers and telco operators** by presenting how 5G provision and characteristics can further reinforce the use of UAVs and their applicability in various markets and actions.
- **The Acedemia, Research Communities and funding EC Organisation** by presenting the market conditions, UAVs technical advances and regulatory framework and how they are all efficiently linked to 5G technology and the project's activities.
- **The Project Consortium** by summing up the project objectives and results from a market, regulatory and business perspective, since D1.7 provides an updated market, regulatory and 5G-UAV business related framework, along with recommendation and future pathways, in which all partners have contributed.
- **The general public** to obtain a better understanding of the UAV existing market areas, the existing regulatory framework, 5G characteristics and opportunities, UAVs business and market new potential when combined with 5G technology.

1.4 Scope of the Analysis

This document provides an updated overview on how the coupling of 5G and UAVs, either under the existing UAVs markets or in news ones, following the new EU UAVs legal framework and relying on the results and knowledge gained by 5G!Drones trials, can lead to additional business processes, markets, products, and services, with new social and financial dynamics.

The market and regulation analysis presented in this document targets to provide an update on the commercial and governmental UAV services, while military services are considered as out of scope. It also links the market characteristics of the market areas tested under 5G!Drones project with the new potential and trends of these markets originating by UAV evolution, sufficient regulatory framework and 5G advent.

The regulation section puts special emphasis on latest EU regulation (EU legal framework changes in 2021 for facilitating and securing UAVs commercial and non-commercial use) and the three countries where 5G!Drones trials were conducted (Finland, France, and Greece), setting the EU regulatory framework in which UAV markets operate.

The 5G impact on UAVs, their markets, services and business processes are also presented in a way where new opportunities are highlighted, recommendations and good practices documented, and stakeholders' opinion, as a result of partners' participation in 5G!Drones and UCs, are well addressed. Future pathways along with new research opportunities are also addressed.

2 UAVs Market and Business Areas

2.1 Overview of UAVs Market and Services

The purpose of this chapter is to offer a detailed and updated analysis of the current status of the UAV markets and UAVs applicability worldwide, both in commercial and non-commercial areas, with focus on the latest evolutions and usages arose over the last two years (many of which have been triggered, affected or even formed due to COVID-19 impact).

Over the last years, drones are in the frontline of several sectors and services. Drones are being used massively in domains giving the chance to the users to facilitate their business in detail. This massive use of drones did not leave than indifferent athletic events of the world such as the 2020 (2021) Olympic Games in Tokyo. An impressive drone show was prepared by the organisers in order to provide the spectators the most comprehensive picture of the opening ceremony storyline.

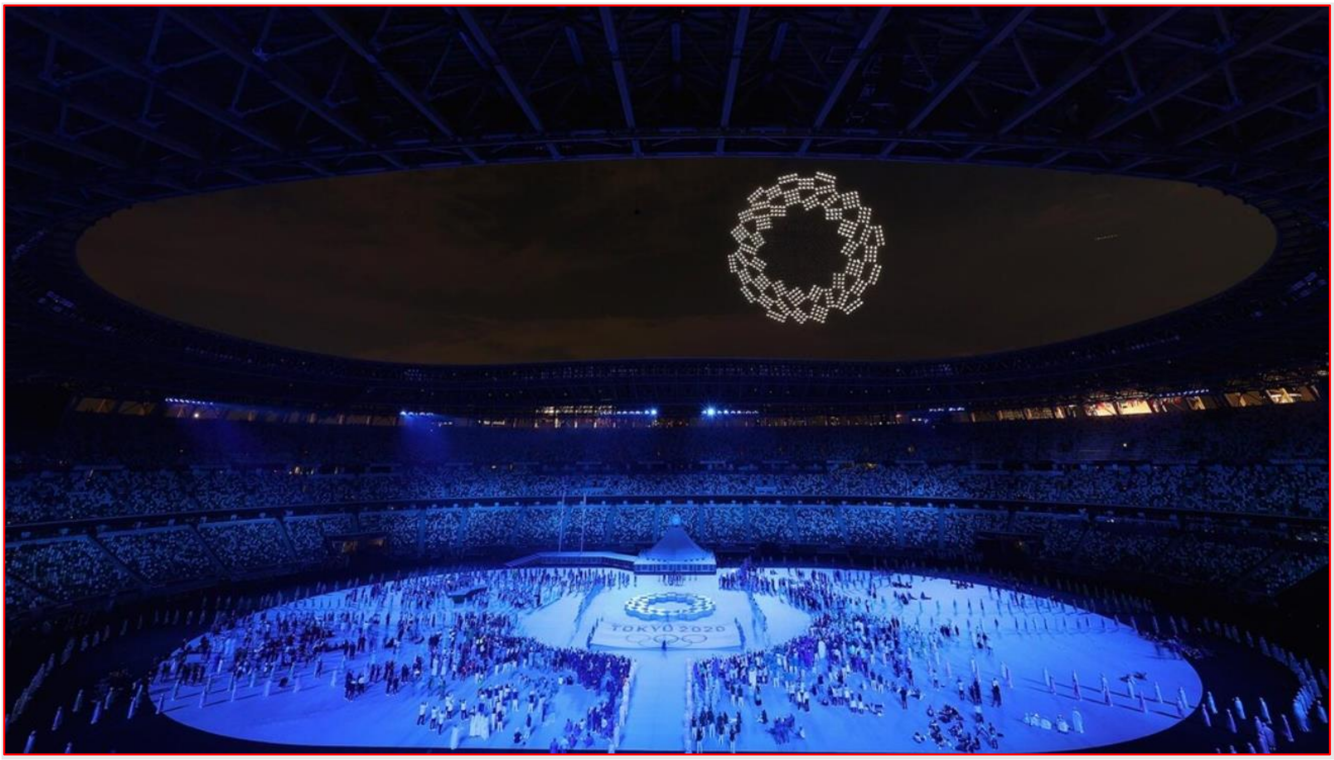

Figure 1 Drones in the 2020 Olympic Games Opening Ceremony[1]

This utilization of drones in such an impactful event and in such an effusive way shows us that drones play a significant role in current everyday life both for entertainment, social and business purposes. Apart from the sport industry drones are now used in different commercial and governmental areas and sectors such as infrastructure, logistics, transportation, agriculture, broadcasting, surveillance, health reasons and for rescue. The most important of these areas will be analysed in the following sub-chapters of this document, showing the existing potential of UAVs given that only a fraction of UAVs potential (in most cases much less than half) is used today (Figure 2).

[1] https://olympics.com/ioc/news/spectacular-intel-drone-light-show-helps-bring-tokyo-2020-to-life-1

Figure 2 EY Survey showing that only a fraction of UAV potential is used. [2]

The drones-UAV industry was not always that developed. The big step happened back in 2015[3] when the Federal Aviation Administration[4] (FAA) gave permission to several enterprises with hundreds of different operational scenarios to use drones. However, beyond this triggering event for UAV industry development, even recently the UAV potential is only partially exploited by SMEs and Innovative start-ups, but also by the relevant industry in general, as an EY survey demonstrates (Figure 2). This means that the Drone market is expected to further grow in the next few years, as it is well described in the following figure (Figure 3), which shows the commercial drone allocation in Europe and expected market size evolution and growth.

[2] https://assets.ey.com/content/dam/ey-sites/ey-com/en_ru/topics/advisory/ey-uav-survey-eng.pdf

[3] https://www.businessinsider.com/commercial-uav-market-analysis

[4] https://www.faa.gov/uas/

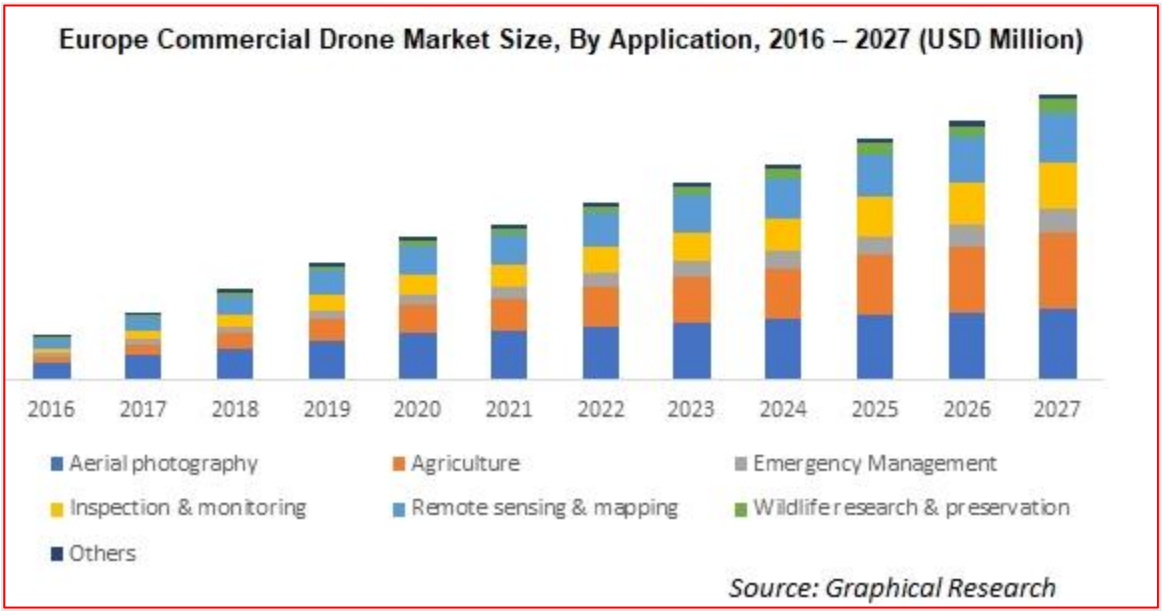

Figure 3 Europe Commercial Drone Market Size[5]

The commercial drone market size in Europe has surpassed 3 billion dollars in 2021 and is expected to raise more than 10% in CAGR by 2027.

Investments in start-ups indicate significant global interest on both, the manufacturing, and the value addition services side of the spectrum. Analysts estimate that up to 55% of the private equity (PE) investments worldwide occur in the manufacturing side, and approximately 45% towards the Value-Added Services (VAS) side (Figure 4).

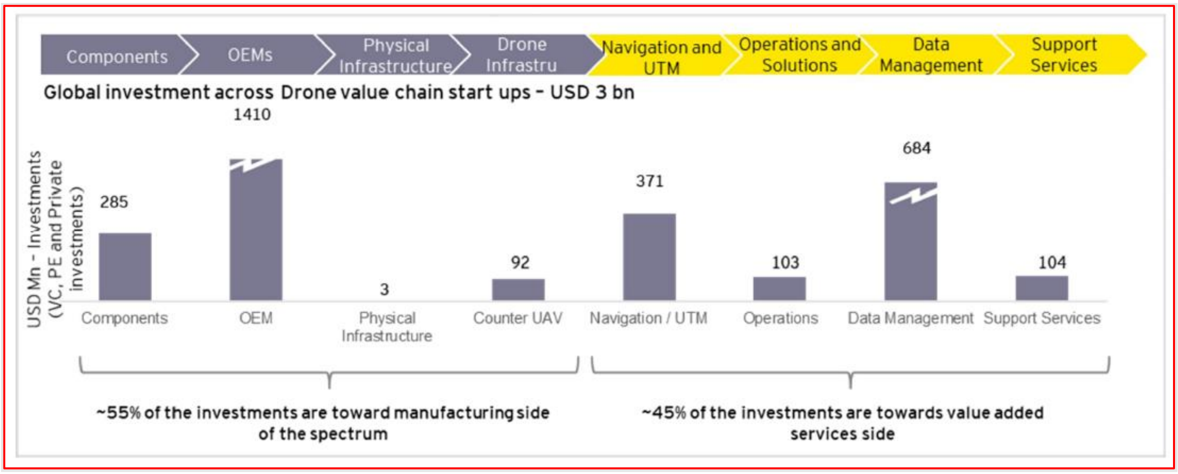

Figure 4 Europe Drone Market Size and Investments[6]

[5] https://www.graphicalresearch.com/industry-insights/1016/europe-commercial-drone-unmanned-aerial-vehicle-UAV-market

[6] https://www.droneregulations.info/index.html

According to DRONEII, the drone market is segmented in three different sectors[7]:

- **Hardware**: includes companies generating revenue with unmanned aerial systems and additional component & systems. Not included are counter drone system manufactures and passenger drone manufacturers.
- **Software**: includes companies generating revenue with software for workflows & data analytics, fleet & operation management, UTM-systems, flight planning and navigation & computer vision.
- **Services**: includes companies generating revenue with business internal drone operations, drone operations to thirds, system integration, engineering and advisory and education, simulation & training.

According to DRONEII's Drone Market Report, the global drone market is worth an estimated US$30.4 billion in 2022. It's a great number poised for steady growth. DRONEII forecasts that the commercial drone market will experience a CAGR of 9.4% until 2026.

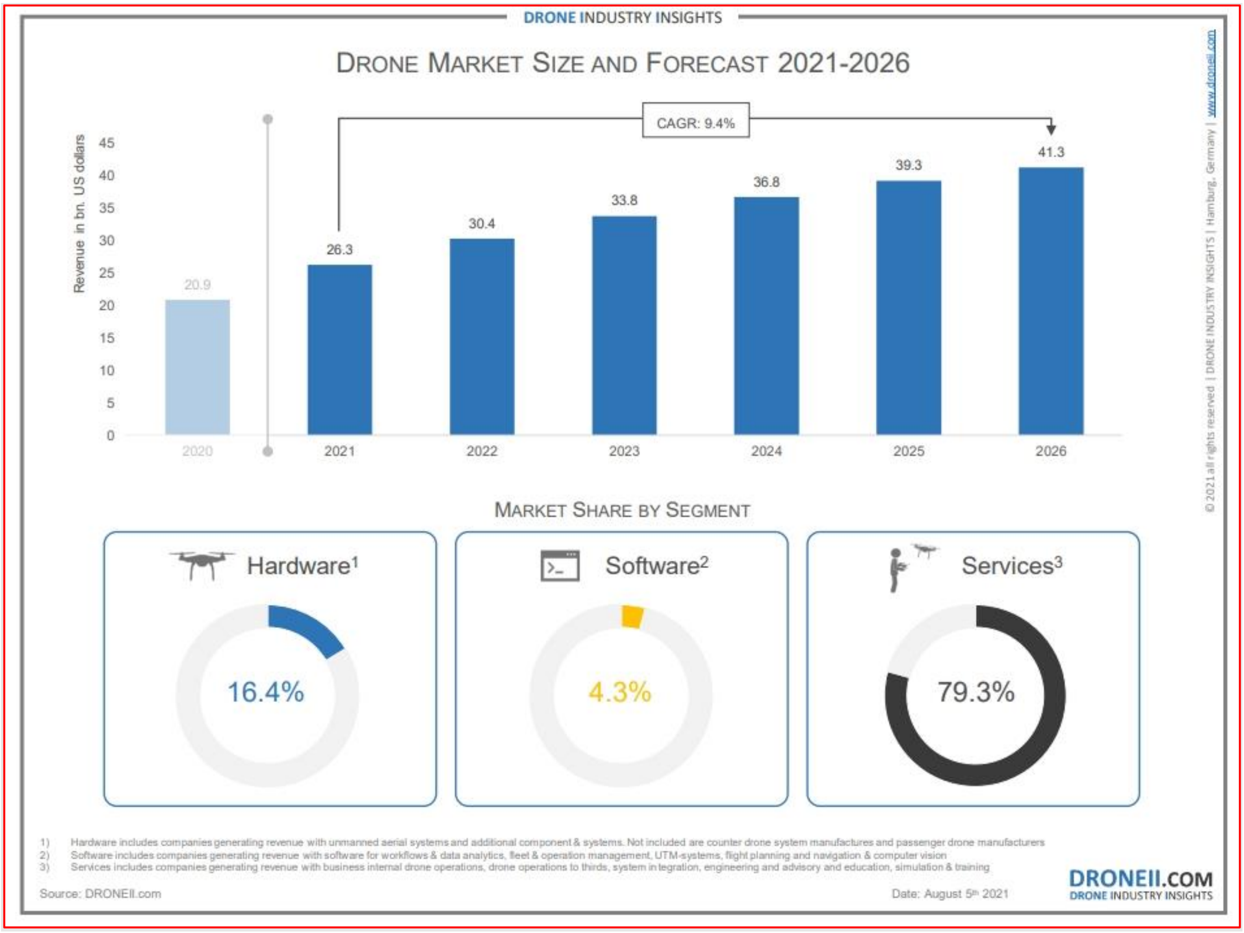

Figure 5 Drone Market Size and Forecast[8]

[7] https://droneii.com/wp-content/uploads/2021/08/drone-market-in-2021-2026.pdf?goal=0_8e282c8de0-4a42f36706-261979470&mc_cid=4a42f36706&mc_eid=fdc7e32b9f

[8] www.DRONEII.com

According to DRONEII's research (Figure 6), Asia is the fastest growing market, with Europe and North America close behind. DRONEII points out that the expanded time frame – until 2030 – allows for new regulations like BVLOS flight and remote ID to be enacted, and drone industry applications to scale accordingly[9].

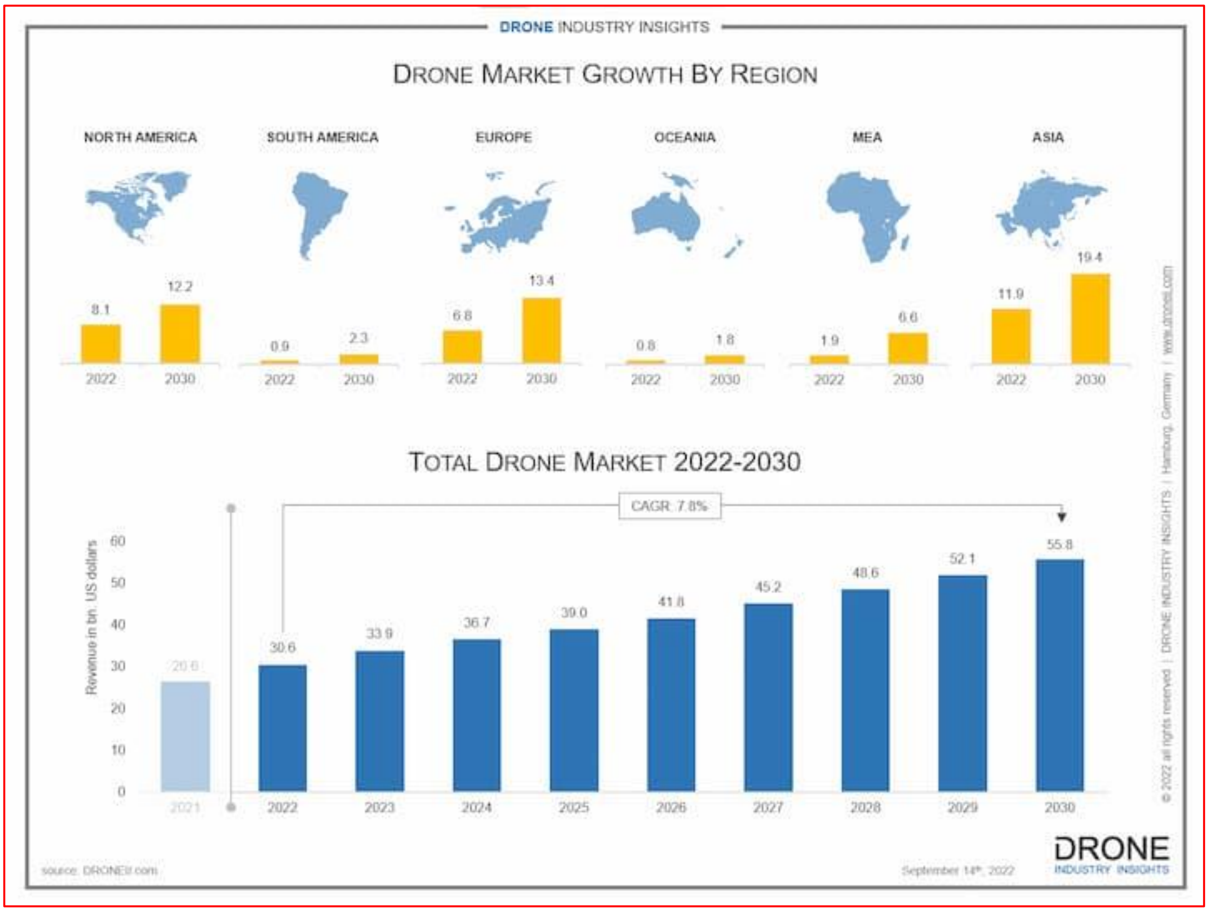

Figure 6 Drone Market Size and Forecast (2022)[10]

In order to provide the reader a better understanding of the market potential and value, a definition of the drone market actors is required (Figure 7). The most important actor of the drone industry is the regulatory framework. As the industry grows, more and more pressure in the related authorities comes to surface, that is why the regulation framework plays the most important role. The second most important actor is the hardware providers. As the drone ecosystem keeps growing and growing a higher demand of high-quality drone equipment is needed in the quickest time. Additionally, more third parties' manufacturers develop software and hardware material, providing the biggest variety and offering the broadest possible quality, in order to meet the even higher demand.

9 https://dronelife.com/2022/09/26/droneii-drone-market-report-where-the-drone-industry-will-grow-the-fastest-by-2030/

10 https://dronelife.com/2022/09/26/droneii-drone-market-report-where-the-drone-industry-will-grow-the-fastest-by-2030/

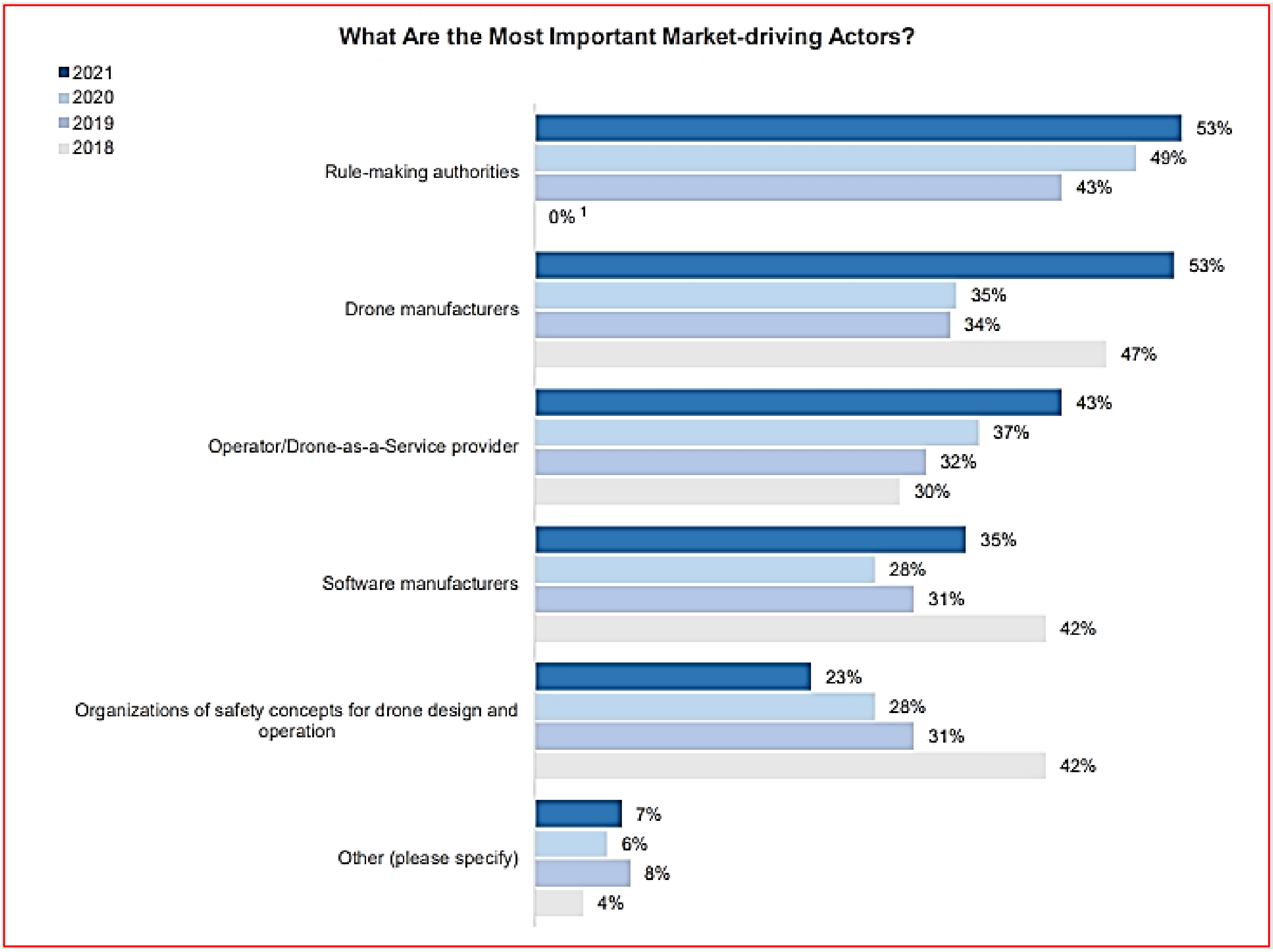

Figure 7 Drone Market-driving Actors[11]

In the same research, conducted by DRONEII, participants were asked about the reason they use drones in their enterprises.

[11] https://droneii.com/wp-content/uploads/2021/09/the-drone-industry-barometer-2021.pdf?goal=0_8e282c8de0-204fc56c3f-261979470&mc_cid=204fc56c3f&mc_eid=fdc7e32b9f

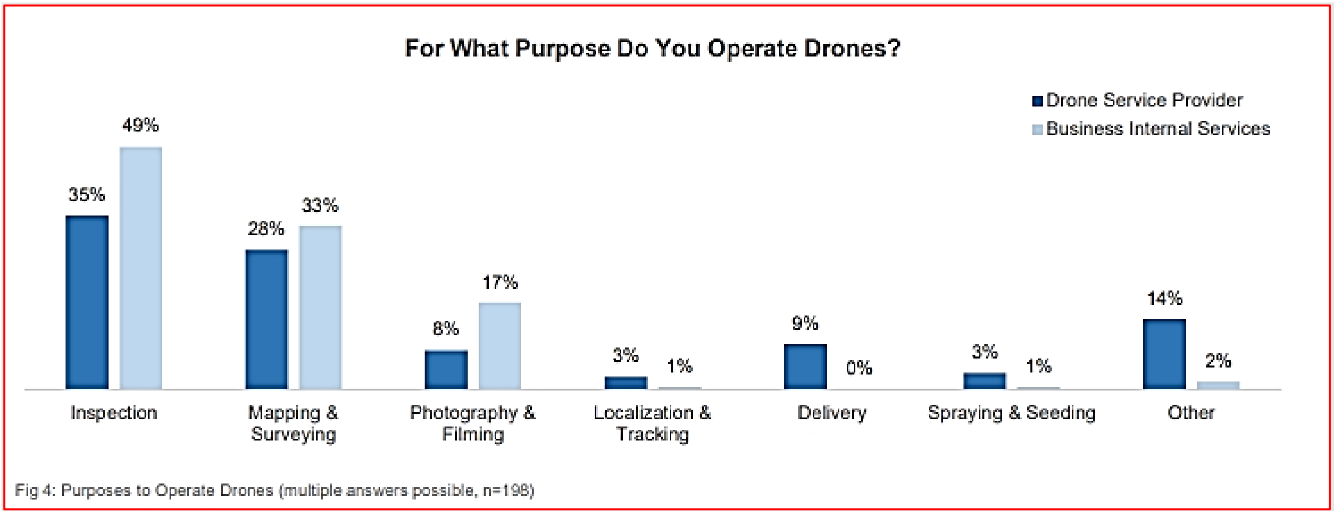

Figure 8 Purposes of Drone usage[12]

As it can be clearly seen in Figure 8, most of the drones are being used for both drone service providers and for business internal services for inspection reasons. The second most popular answer is mapping and surveillance, while the photography and the filming options comes third. Lower percentages, have the localization and tracking, the delivery services and the final one for spraying and seeding. Finally, there is an answer called “Other” which summarises all the rest drone activities.

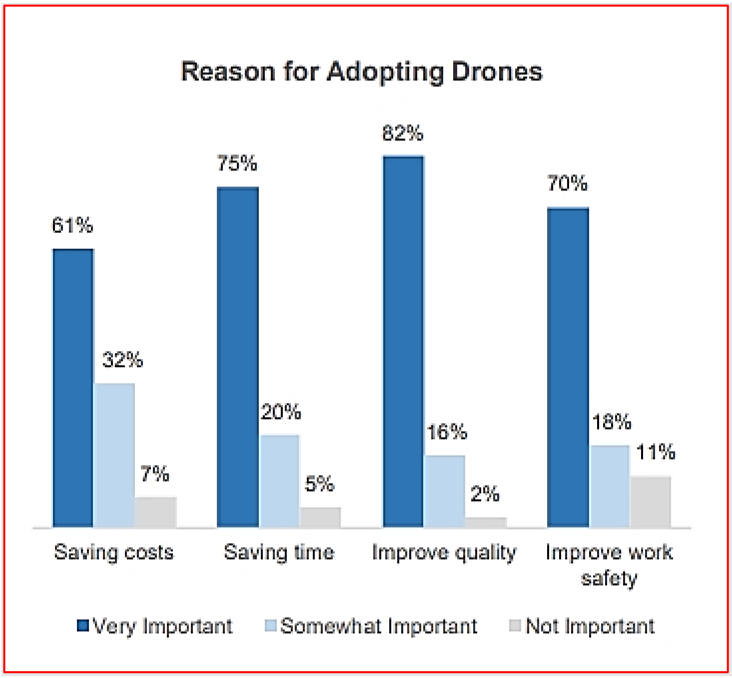

Figure 9 Reasons to have a Drone

Another significant part of the same research shows the importance and the dimensions that drones have in enterprises worldwide. As it can be summarised in Figure 9, the quality aspect along with the saving time aspect are the first ones. That situation shows us the versatility and the interoperability that

12 https://droneii.com/wp-content/uploads/2021/09/the-drone-industry-barometer-2021.pdf?goal=0_8e282c8de0-204fc56c3f-261979470&mc_cid=204fc56c3f&mc_eid=fdc7e32b9f

a drone may give to the business environment. It is also important to mention that improvements in safety and cost efficiency have also acquired a lot of answers, advocating more to the importance of drones.

Another drone research conducted by PWC for the British authorities[13] highlights the impact of drones and how this “flying technological gadget” can offer different services and opportunities in a wide spectrum of business, governmental, industrial and entertainment purposes. All these, sectors will eventually boost the economy of the country (United Kingdom), which will not only lead to the increase of the gross domestic product but will also improve the unemployment rate as it will open new opportunities in the job’s sector. Figure 10 gives a brief overview on how drones will affect the British economy by 2030.

Figure 10 British economy influenced by drones[14]

Although drones are getting more and more popularity in recent days, there is still several “blurry sceneries”, in the drone industry. A typical example is the following recent incident.

On Saturday 22nd of January 2022 the premier league’s clash between Brentford and Wolves has been interrupted for more than 20 minutes due to an unknown drone flight above the Brentford’s Community Stadium in west London. The incident was so unexpected that even a police helicopter flew in order to move the unknown drone away. During the match a Brentford’s spokesperson stated “"Given the risks, the match officials and the stadium safety team followed agreed protocols to suspend the game and remove both teams from the pitch”[15].

[13] https://www.pwc.co.uk/intelligent-digital/drones/Drones-impact-on-the-UK-economy-FINAL.pdf

[14] https://www.pwc.co.uk/intelligent-digital/drones/Drones-impact-on-the-UK-economy-FINAL.pdf

[15] https://www.skysports.com/football/news/11748/12522672/brentford-vs-wolves-drone-stops-play-at-premier-league-match

Figure 11 Drone interrupting a Premier League game[16]

The question is now what forced the official to suspend the match for some minutes. The answer here is not clear but at least we can conclude in some points. Maybe this unidentified drone has tried to stream the match on some online platforms, something that of course is illegal and against the official broadcaster which provides the match rights all over the world. Another explanation is that this drone could have set in danger both players and the spectators of the game[17]. The final explanation has a close relationship with the proximity of Brentford's stadium with Heathrow airport. A flying drone in the area of an airport can cause several problems[18]. Up to now there is no official statement about the reason behind this unidentified flight. However, from a single incident many safety dangers may arise. A situation that on the one hand restricts drone enthusiasts and operations and on the other hand leads the discussion of safety framework and extra measures.

2.2 UAVs Business Areas

Drones, or preferably UAVs by the professionals, are being used for commercial purposes since the 1980s[19]. As the world progresses the drones expand their utilities and nowadays have the ability to offer their services in a large spectrum of operations. This fast-track increase of drones in businesses and industries not only boosted the operations in the already established enterprises but helped to the emergence of new ones. In the following sections we try to give an overview of the most influenced by drones' commercial areas.

[16] https://www.thesun.co.uk/sport/17408236/brentford-wolves-stopped-drone-stadium/

[17] https://www.goal.com/en/news/drone-flies-above-stadium-during-brentford-v-wolves-match-as/blt56f5aa989b78dad4

[18] https://www.itv.com/news/2022-01-22/brentford-v-wolves-halted-after-drone-spotted-hovering-above-community-stadium

[19] https://www.technologyreview.com/2016/07/20/158748/six-ways-drones-are-revolutionizing-agriculture/

2.2.1 Commercial Areas

2.2.1.1 Infrastructure Inspection and Construction

2.2.1.1.1 Market characteristics

Drones are not utilised only for entertainment purposes. They can operate under extreme and unapproachable environments. Drones in the past few years have entered the infrastructure and construction zone to assist the operations in the field. Drones, among others, can improve communications, provide real-time view, and provide data that cannot be easily acquired without them. Also, drones do not assist only the workers but also project managers, superintends and executives (Figure 12).

Figure 12 Job roles assisted by drones[20]

The following section summarises in brief the most important fields that construction can be assisted by drones and existing trends.

[20] https://www.dronedeploy.com/blog/rise-drones-construction/

Figure 13 Drone operating in construction sites[21]

2.2.1.1.2 Trends

- **Topography and mapping**

Starting a new construction site means that a huge number of topographical blueprints are needed in order to provide a clear picture of the site and the land conformation. This bureaucratic situation costs both in time and money. Besides that, this type of blueprints provide data for a specific time and under specific conditions, which will be completely different when a project finally starts. All the previous uncomfortable situations can be easily facilitated by a drone.

[21] https://www.geospatialworld.net/blogs/an-aerial-view-of-the-future-drones-in-construction/

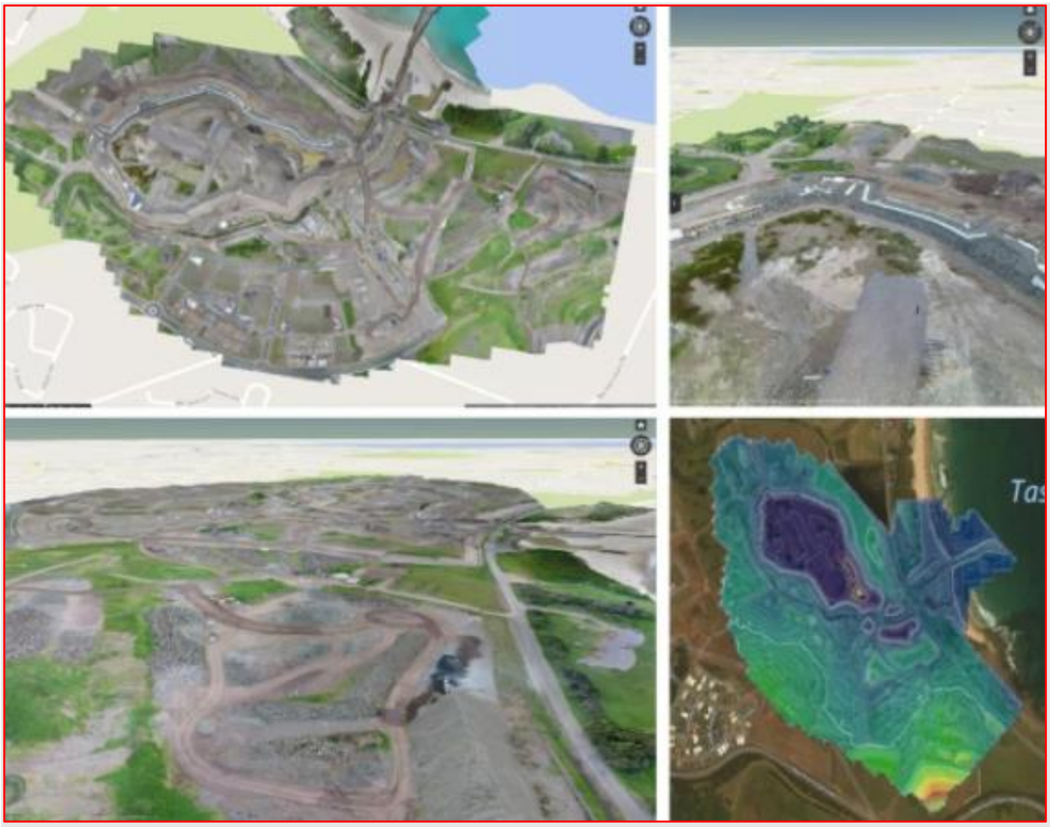

Figure 14 Drone Survey visuals[22]

Drones supplied with sensors, multispectral cameras and LiDAR payloads can give the related stakeholders a very clear view of each inspected area[23]. Due to their ability to map vast quantities of land, drones can exponentially cut down on time spent visualizing a site's topography[24] (Figure 14). Drones can also provide 2D and 3D models of each area. All these imaging procedures can have a serious impact on a project's process.

The impact can be translated to reduced time on fulfilling research before a construction project and to less spendings because less manpower will be needed to carry out a topography survey of the selected area. All the data collected by s drone are based on the latest technology available which means that the measurements are more precise and up to date. Drones can also be used after a project's initiation and retrieve data that may diversify the initial strategy. Finally, the aerial mapping that a drone provides can offer access to areas that workers and vehicles cannot easily go. So, the drones at this point bridge the gap between remote areas (Figure 15).

[22] https://www.propelleraero.com/blog/drones-changing-game-topographic-surveying/

[23] https://wingtra.com/drone-mapping-applications/surveying-gis/

[24] https://www.bigrentz.com/blog/drones-construction

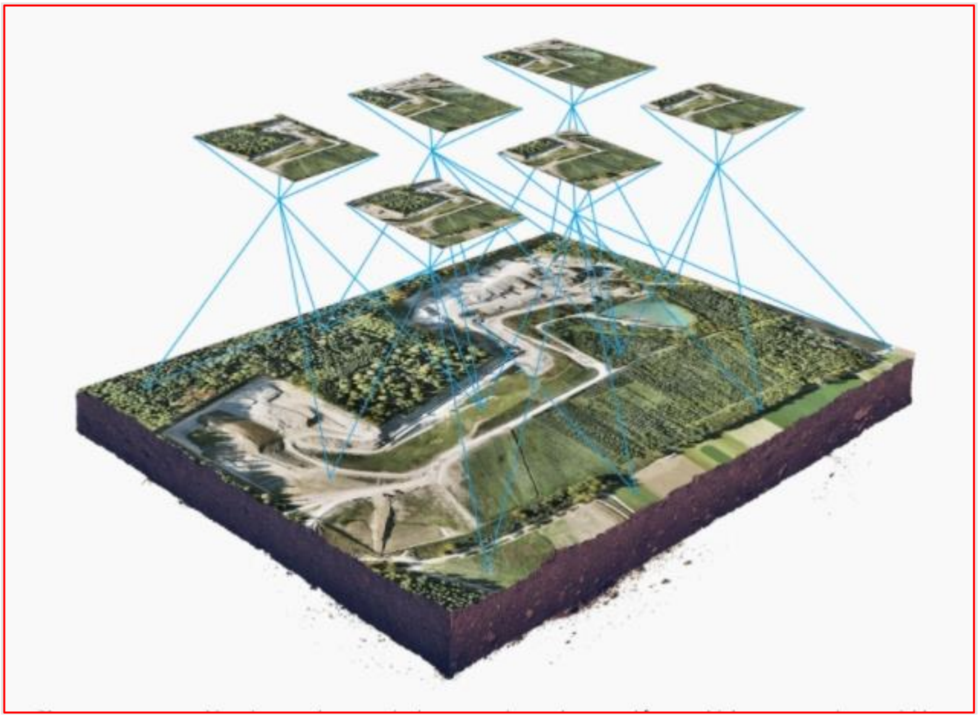

Figure 15 The site from multiple points[25]

- **Health and safety reasons**

The health of the construction personnel is indisputable. However, workers are forced to work under difficult circumstances, extreme weather conditions, in heights and in unsteady platforms, and in remote areas where they put themselves in danger. Following a strict safety regulatory system may be lifesaving on some occasions, but sometimes it may not be enough. Drones can be used for remote inspection and dedicated missions. As we have described previously drones can be equipped with sensors that can easily scan the surface and identify structural failures[26] that can put the workers life in danger. Drones can also be equipped with additional hardware equipment that can pull large and unwanted material that block the operations in the construction site.

Furthermore, drones can emerge and provide live data from an incident. In other words, drones will replace the personnel if a construction site faces a serious danger like a flood. Sending human resources to record the damage caused in a flooded construction site is really dangerous, on the other hand sending a drone is safer and can have better results. Construction sites are highly dynamic and kinetic environments with lots of moving parts. Power tools, heavy machinery, building materials, overlapping work crews—any one of these elements can be seriously dangerous if not minded properly (Figure 16).

The bird's-eye view afforded by drones makes it easier than ever to do just that, enabling project managers to efficiently ensure that conditions remain stable and safe on the ground. Drones can also monitor construction sites while work is in progress, keeping an eye out for unsafe work conditions and catching hazards before they pose a direct threat to life[27].

[25] https://wingtra.com/drone-mapping-applications/surveying-gis/

[26] https://www.iotforall.com/construction-site-safety-with-drones

[27] https://onekeyresources.milwaukeetool.com/en/construction-drones

Figure 16 Workers and drones' collaboration[28]

- **Remote monitoring and inspection/surveillance**

Another valuable aspect of drone operating in a construction site is the remote monitoring and the inspections that can provide. As we have described in previous sections, drones can provide an extensive aerial view of each construction site that give a clear picture on the work's progress. Each work in progress consists of different stages. Each stage has specific goals and achievements that have to be accomplished in order to track the progress of the project. Drones can easily monitor these construction phases and provide data about the status of each sub-construction of the site. This procedure validates the already performed work and ensures the stability of next phases[29].

A construction site is without a doubt a very complex and complicated work in progress. This means that constant track of the facilities is a prerequisite for the success of the project. Drones can assist in the documentation and in the project and provide detailed progress reports. Also, drones can provide both contractors and the clients with real time data about the site progress. Besides the monitor mechanisms that a drone can offer, drones are being utilised and for inspection purposes.

[28] https://blog.creativesafetysupply.com/using-drones-to-improve-workplace-safety/

[29] https://www.vanguardwireless.com.au/blog/item/47-drone-construction-safety

Figure 17 Drone monitoring procedure[30]

Apart from monitoring the site's progress, drones can be used also for inspection and surveillance purposes. Construction sites are susceptible to damages that need to be fixed in a short time after they occur. The constant carriage of machinery, materials, and tools, along with the extreme weather conditions and the human factor can sometimes damage the work in progress. A work that will need repairing when the damage is spotted. For that purpose, drones consist of the most viable solution because they are the fastest and the cheapest means to facilitate the situation. Within a short time, drones provide all related data about the size of the damage by surveying the site, following specific methodology/process (Figure 18). At this point, it is worth mentioning that many sites are in remote areas or have enormous heights that block the human inspection. Drones using enhanced cameras can provide thermal images or 3D illustrations that give insights about the area that faces the problem. This procedure offers workers the chance to initiate the repair plan faster by acting proactively and not after the situations become worse.

A common customer of this type of service may be telecommunications operators, in particular cellular networks characterised by the dispersion of numerous base stations over large areas. In case of sudden and violent atmospheric phenomena leading to damage or destruction (e.g. antenna systems, masts, etc.), the initial vision of the situation made with the use of drones may be used for a better and faster operator's local intervention teams' response in order to remove the damage and restore the full performance of the network, especially related to providing the access to emergency services to the customers, which is one of the top priority services (Figure 19).

[30] https://millenniumuav.com/remote-inspections/

Figure 18 Drone Inspection procedure[31]

Figure 19 Drone inspects a chimney[32]

[31] https://forcetechnology.com/en/articles/inspection-using-drone-technology

[32] https://forcetechnology.com/en/articles/inspection-using-drone-technology

- **Equipment tracking**

Besides the human resources, the second most important aspect of a construction site is the equipment. Equipment which consists of large machinery, tools and vehicles that cost millions and are of utmost importance for the progress of the project. This equipment is scattered all over the chaotic environment of the construction site. This chaotic situation may force the project to several delays due to the lack of identifying easily the correct tools. The problem gets bigger when this equipment has to be transferred through different contractional sites.

Drone technology can also provide a solution for this situation. A drone flight can easily spot if a tool is in the right place (tracking mission) and inform the personnel about its exact location (Figure 20). This drone attribute can also be used as an anti-theft mechanism. Sometimes enormous construction sites cannot be easily secured, so the equipment might stay unprotected. Furthermore, a drone is able to give details about the condition of each tool and save time if a tool needs repairing. Drones can also, be useful to the rental companies by providing diagnostics and data from the contraction site[33].

Figure 20 Drone in tracking mission[34]

[33] https://www.bigrentz.com/blog/drones-construction

[34] https://www.geekwire.com/2019/echodyne-univ-washington-assist-darpa-aerial-drone-surveillance-test/

2.2.1.2 Agriculture, forestry, and natural environment management

Utilizing drones for agricultural purposes is not a new idea. Since 1990s drones (Unmanned remote-controlled helicopters in specific) have been used by Japanese farmers to for spraying rice farms[35]. However, in recent years there has been a significant rise in the use of drones for agricultural purposes. This rise is so large that agriculture is one of the most important sectors in the drone industry, with drone powered solutions estimated to reach a market value of $127 billion within the next few years (Figure 21).

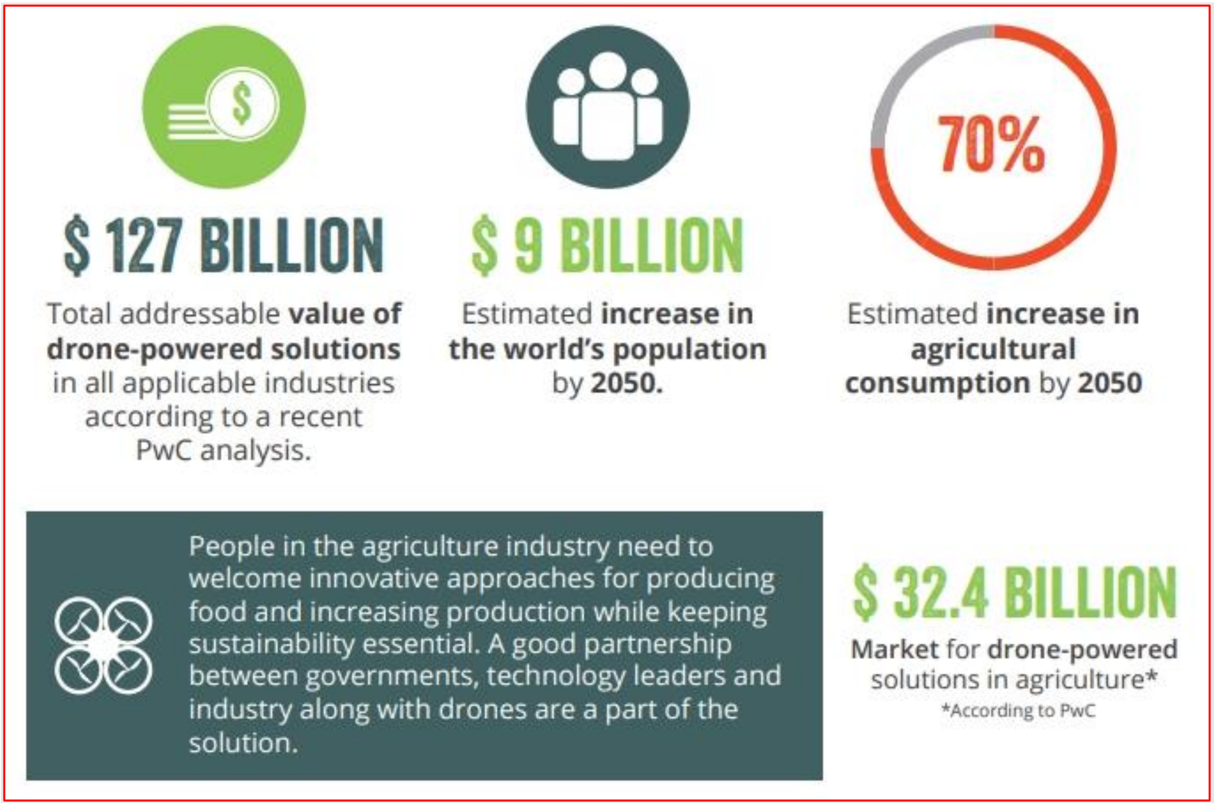

Figure 21 Drones and agriculture overview[36]

2.2.1.2.1 Market characteristics

The world's population is expected to reach the number of 9 billion by 2050[37] and for the same period the predictions of the experts predict that the levels of agricultural consumption will increase 70%[38] (Figure 21). Besides that, climate change is forcing more and more farmers to adapt in extreme and unpredictable circumstances, which lead them to lose a significant amount of their annual incomes. These two variables mean that the conventional farming techniques are not enough to support the agricultural industry. So, it is of utmost importance to change the way that farms operate and the interaction between earth and human in order not only to decrease the economic loss but also protect

[35] https://www.growingproduce.com/vegetables/ag-robots-and-drones-may-be-a-10-billion-market-by-2022/

[36] https://ussoy.org/wp-content/uploads/2018/01/57505_USDAdraft_USsoy.org_Drone_Technology_Infographic5.pdf

[37] https://www.researchgate.net/publication/358280649_DRONE_in_Agriculture_article

[38] https://www.fao.org/documents/card/en/c/I8494EN

both farms and farmers from the side effects of the climate change[39]. A sustainable approach in the management of agricultural fields could be the key for reversing the previous mentioned situation[40]. Drones are here to offer a wide spectrum of solutions, towards this sustainable transformation. In general, drones can be used to save time, crop yields, for monitoring purposes and for seed planting[41].

In the trends section below, we describe in a more detailed way the way drones can boost the agricultural sector.

2.2.1.2.2 Trends

Drones are more often used to revolutionize the traditional farming procedures and help farmers to improve their capabilities. The following paragraphs summarize all the possible ways that a drone can assist farmers in their job as part of the newly used human-drone interaction on the fields[42] (Figure 22).

Figure 22 Human – drone interaction in the yield[43]

- **Soil and field monitoring**

The basic principle for a farmer in order to have a fine crop is to take care and protect the earth and the yields that he owns. A yield that faces several dangers such as extreme weather conditions and the uninterruptedly sowing by farmers in order to meet the market's high demand and maximize their incomes may not be in the condition to produce the best possible outcome (crop). A drone enabled approach by the farmers may help them to retrieve data and adapt their farming policy (and also be better informed and act proactively).

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[39] https://www.precisionag.com/in-field-technologies/drones-uavs/the-role-of-drone-technology-in-sustainable-agriculture/

[40] https://www.ipcc.ch/

[41] https://www.researchgate.net/publication/355125734_Drone_-Applications_in_Agriculture

[42] https://consortiq.com/uas-resources/how-drones-are-growing-the-agricultural-industry-with-soil-analysis

[43] https://intellias.com/collecting-and-analyzing-drone-imagery-for-crop-monitoring/

Of course, it is impossible for anyone to predict extreme weather conditions, but a drone can give them the chance to manage their lands and potentially diversify their crops. For instance, in recent years farmers prefer to use synthetic soil rather than natural. It is a technique that allows farmers to boost their production. However, this technique in the current agricultural environment requires a constant amenity of data for continuous monitoring. These very useful and insightful data can be acquired by drones in collaboration with AI procedures.

The use of global positioning system (GPS) technology, together with geographic information system (GIS) tools, form a large part of these precision agriculture practices allowing fine-scale monitoring and mapping of yield and crop parameter data within fields. These provide more intense and efficient cultivation methods, which can help farmers adjust fertilizer prescriptions or identify crop diseases before they become widespread[44]. Also, the topography of fields from RGB Imagery assists farmers to position and segregate the crops to maximize drainage, follow natural land runoff, and to avoid water-logging[45] (Figure 23).

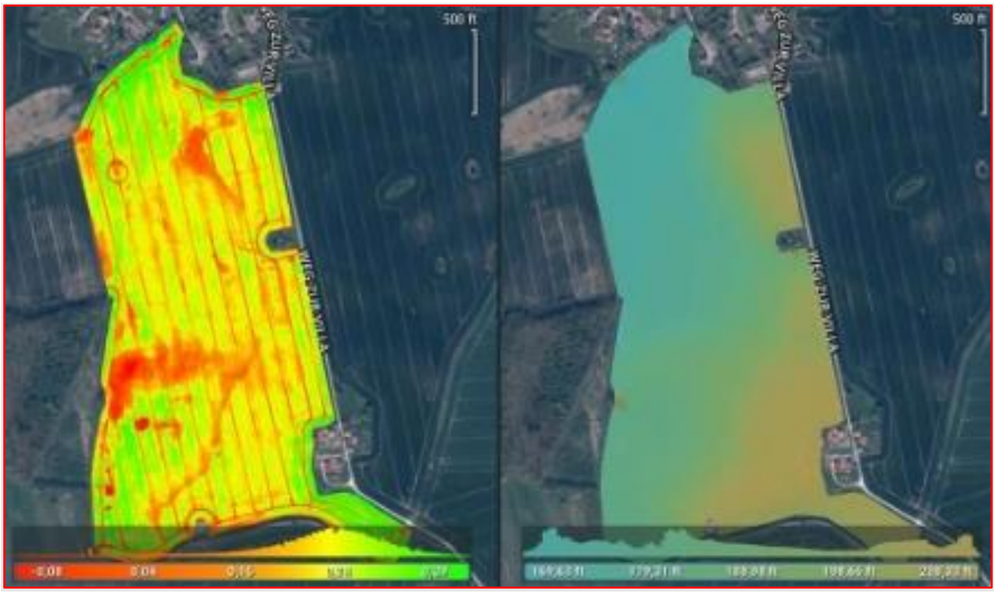

Figure 23 Drainage and irrigation mapping

- **Crops health assessment**

A fundamental element of the agricultural sector is the immediate and the most accurate evaluation of crops and tree health. This procedure gives the chance to farmers to enable their treatment plan at an early stage in order to save the majority of crops and production. Furthermore, a farmer that uses drones to monitor the health of their plantations can easily sport the effectiveness of the treatment, and apply alterations, if needed. Drones that use update lighting and imagine processing mechanisms play a contributory role to the smooth daily routine of a farmer. Such a mechanism is the Normalised Difference Vegetation Index (NDVI)[46] which evaluates the plant's status based on a detailed colour palette. For instance, this procedure can indicate to the farmer which plant faces problems during its growth, in order to deal with it, without causing any other problems to the rest of the plantation. Apart from that,

[44] https://www.precisionag.com/in-field-technologies/drones-uavs/the-role-of-drone-technology-in-sustainable-agriculture/

[45] https://www.equinoxsdrones.com/agriculture

[46] https://www.croptracker.com/blog/drone-technology-in-agriculture.html

drones using simple cameras can provide the farmer accurate image location to the millimetre[47], without taking into account any problems from clouds or poor light conditions.

NDVI is just one of vegetation indices, the simplest and the most popular, however. There are also hand-held NDVI meters giving the instant answer. Vegetation indices are based on the “red edge" effect – for each plant and also for each its development stage there is a reference spectral signature (a shape of spectral characteristics) in visible light and near infrared band, but the abrupt increase from visible red to infrared always exists (Figure 24). Calculation of various indices can give an authoritative answer if a single one gives non-conclusive indication (different indices have different applicability and specific disadvantages – e.g. different results for different time of day, weather, insolation conditions, etc.).

NDVI serves as a measure of nitrogen supply to plants, to the lesser extent of phosphorus and potassium. For other micro- and macro-elements, and for detecting that the crop is attacked by a certain pathogen, spectral analysis of averaged colour spots representing parts of the crop area is insufficient, image quality is required that shows colours and shape of the coloration of specific parts of the individual plants. The remote plant health assessment methods are also used in forestry and plants biodiversity monitoring. The common denominator for this and previous use cases is drone photogrammetry allowing for creation of orthophoto maps to be further processed by various algorithms of images processing. The advantage of drones vs. satellite or airplane photogrammetry is much better resolution (e.g. 1 cm per pixel or better) due to low drone flight altitude.

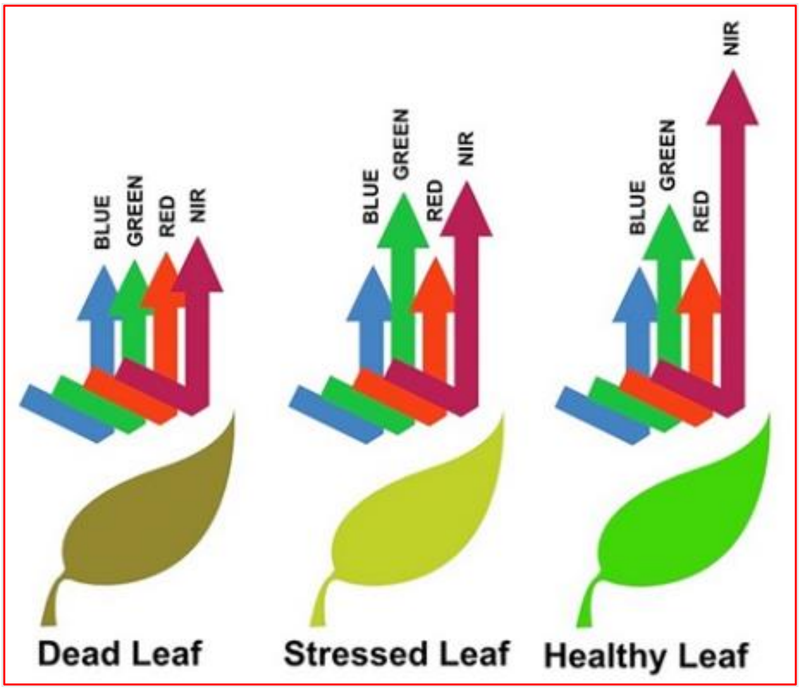

Figure 24 Difference Vegetation Index

- **Indoor farming**

Drones are used also in vertical farming like in companies Aerofarms[48] with a collaboration with Nokia Bell Labs. Also, a company called iFarm[49] has tested drones in indoor farming. The use of

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[47] https://www.futurefarming.com/smart-farming/tools-data/drone-operators-explore-machine-learning/

[48] https://www.aerofarms.com/2021/08/05/aerofarms-and-nokia-unveil-partnership-for-next-generation-ai-enabled-plant-vision-technology/

[49] https://www.youtube.com/watch?v=_xEID613Byw

drones for indoor farming monitoring is considered really new and needs more tests and data for clearly evaluating the actual cost-benefit potential.

- **Crop planting**

Drones nowadays can also provide planting solutions in the agricultural sector. Drone-planting approaches can give a big advantage to the farmers. Drone planting can easily plant seeds or trees in inaccessible places, is more eco-friendly, is cost-effective and does not consume so much time as the traditional planting methods (Figure 25).

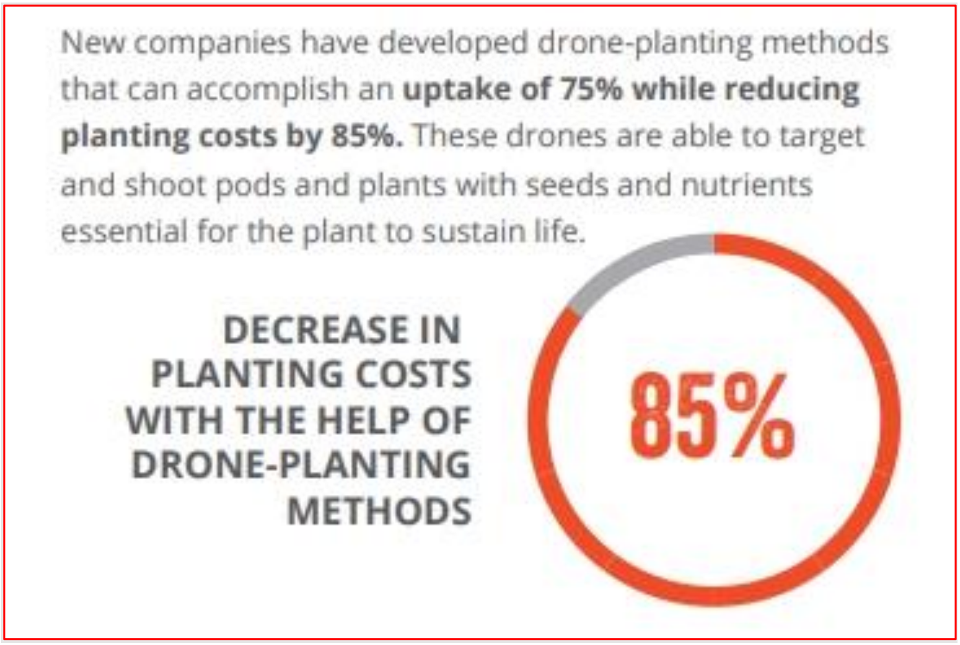

Figure 25 Drone Planting methods benefits[50]

Indicative example is its adaptation by the Canadian reforestation company: Flash Forest[51]. Flash Forest plans to plant 1 billion trees by 2028 in order to regenerate ecosystems. To achieve this goal the enterprise modified drones so they can easily put tree pods into the ground while a specific planting framework is followed. Each pod contains the tree seed along with fertilizers that help the tree to grow up (Figure 26 and Figure 27).

[50] https://ussoy.org/wp-content/uploads/2018/01/57505_USDAdraft_USsoy.org_Drone_Technology_Infographic5.pdf

[51] https://flashforest.ca/

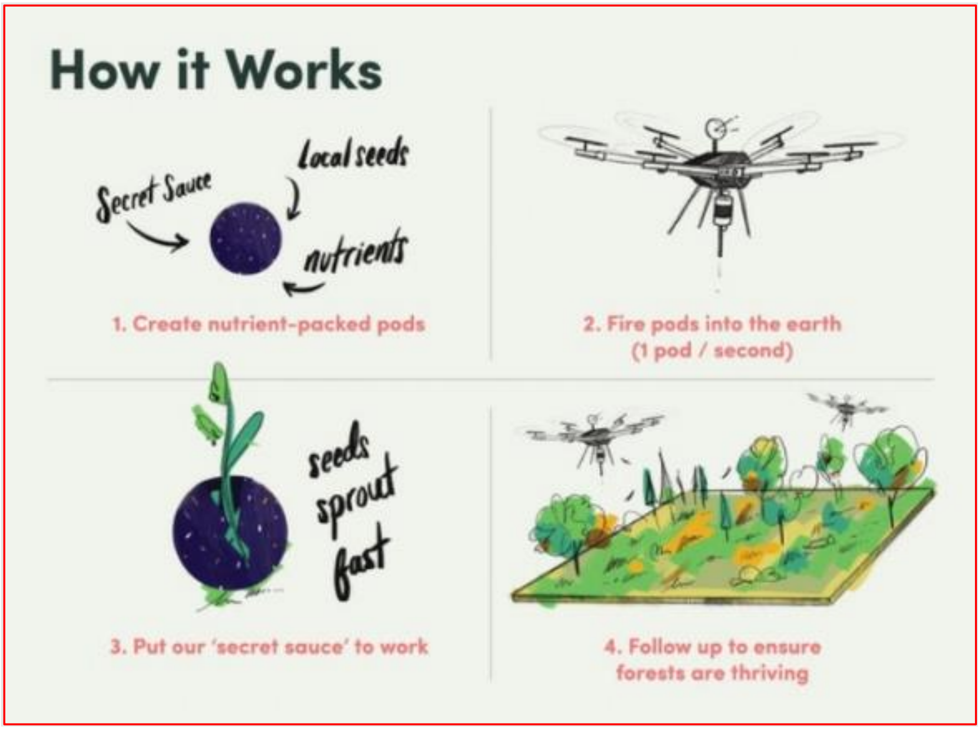

Figure 26 Drone Planting procedure[52]

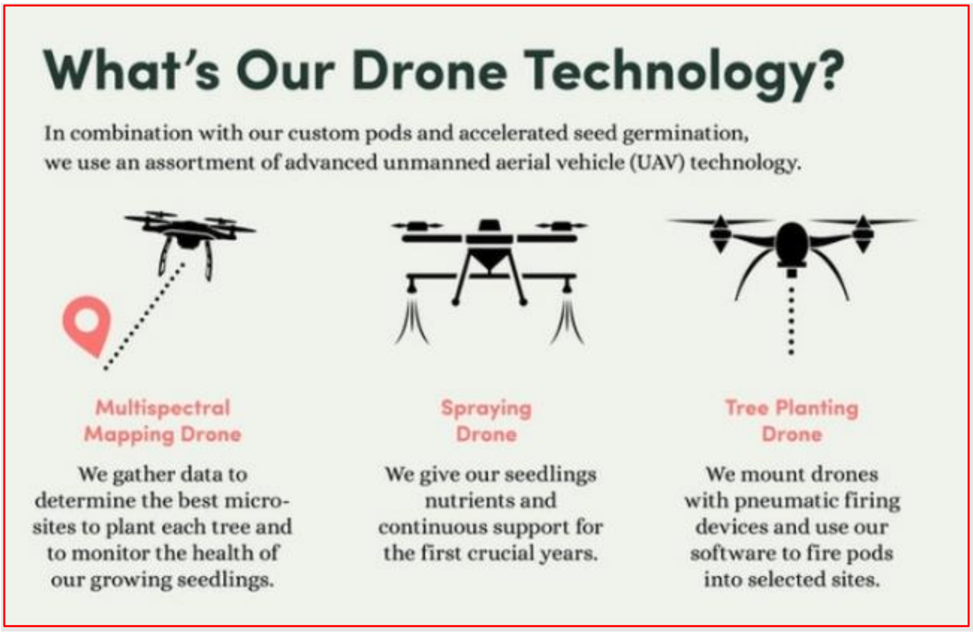

Figure 27 Drone Planting Framework[53]

This framework is very descriptive on how drone-planting mechanisms can assist not only individual farmers but institutions and governments to adapt this methodology on a larger scale.

[52] https://interestingengineering.com/these-drones-will-plant-1-billion-trees-in-just-8-years

[53] https://interestingengineering.com/these-drones-will-plant-1-billion-trees-in-just-8-years

- **Drone spraying**

Spraying plantations using drones is another useful drone application in the agricultural sector. Spraying plantations through drones is a more precise and cost-effective way rather than the traditional one. Drones can use the LiDAR sensor system to easily scan the landscape and adjust their altitude coming closer to the plants and achieve the best possible result of crop spraying. The short distance between the drone and the plant can lead to bigger precision[54] on spraying, increased productivity, shorter usage of chemicals and less air and ground pollution (Figure 28).

However, legislation concerning spraying is not yet homogeneous in all EU countries. Indicatively, in Poland the agro-aviation treatments are extremely limited because they are highly inexact and sensitive to wind (protection of water reservoirs and watercourses, roads, beekeeping areas, keeping the safety/isolation zones around the treatment area, etc.). The minimum allowed treatment area has to be larger than 3 ha. At the same time, the typical foliar dose of pesticide is about 200 litres per ha. In the case of soil spraying, it is even 400 litres per ha. A typical dose for foliar fertilization is 300 litres per ha. It means that spraying drones would have to carry tens or hundreds of tons of working media in large farms. Even if we apply the “per plant spraying” and reduce the doses to 25%, we are still at the order of tons per farm[55].

Figure 28 Drone sprays plants[56]

- **Livestock management**

Drones can be used for remote situational awareness in pastures, but also for automation of health monitoring and adapted feeding of individual livestock animals. In a 1000 cows farm, the AI-based system was developed in which the real-time video was delivered from drone cameras to the image

[54] https://www.businessinsider.com/agricultural-drones-precision-mapping-spraying

[55]https://www.nature.com/articles/d41586-019-00176-zhttps://ec.europa.eu/health/documents/community-register/2017/20171201139325/anx_139325_en.pdf

[56] https://www.xagaustralia.com.au/aerial-spraying

analysis and recognition system able to identify an individual cow, analyse its health status and nutrition needs, and then determine the optimal food dose to be applied[57].

- **Pest/invasive species control and combating infectious diseases in wild animals**

In agriculture, drones can be also used for biocompatible crop pest control by spreading predator larvae/eggs over the crop to attack pests that threaten the crop. In case of natural environment management, especially forests, drones are used for combatting rodents by airdropping poison pellets with rats attractants[58] and for infectious diseases control (eradication of rabies in wildlife by airdropping the oral vaccines)[59]. Drones are also applied to invasive species control trough their detection and monitoring[60], then the relevant means (also with use of drones) can be applied[61].

- **Forest management**

There are multiple applications of drones in the forest or natural environment management area: remote situational awareness (e.g. assessment of damages after natural disasters like wildfires or windstorms, prevention of illegal logging, pouching or fishery), forest inventory management support (remote inventory of trees in forests with the use of LiDAR), fire monitoring, timber harvesting support. In the United Kingdom, Nottinghamshire, there is a visionary project 5G Connected Forest in the Sherwood forest[62], which aims to deploy drone-based “airborne robotic forest rangers” to be used for patrolling of protected and inaccessible forest regions, assessment of forest damages, or search and rescue operations of lost visitors.

- **Support of sensoric data collection**

While being used for cyclic situational awareness flights, drones can at the same time act as flying “data collectors” in areas of poor mobile network coverage, such as inhabited and forest areas usually are – the ground stationary, low power sensors (used in agriculture, forestry, biodiversity and environmental monitoring) can be polled during such “data acquisition flights”, and the “harvested data” can feed the relevant information systems.

As a conclusion, drones are really a big boost to the agriculture, forestry, and environment management sector. Briefly drones can transform them in a more time and cost-effective, environment-friendly, safe, accurate and productive way[63].

[57] https://doi.org/10.1109/IWCMC51323.2021.9498643

[58] https://www.nature.com/articles/d41586-019-00176-z

[59] https://ec.europa.eu/health/documents/community-register/2017/20171201139325/anx_139325_en.pdf

[60] https://wildlifedrones.net/invasive-species/

[61] https://dronedj.com/2022/05/16/after-rats-galapagos-islands-drones-combat-invasive-plants/

[62] https://5gconnectedforest.org.uk/

[63] https://yourdronereviews.com/benefits-of-drones-in-agriculture

2.2.1.3 Drone Deliveries and Logistics

2.2.1.3.1 Market characteristics

As we have already mentioned earlier drones nowadays can be efficient in a variety of sectors and verticals. One of these sections is the logistics and therefore, the delivery processes. Briefly drones and UAVs in general have been proven more than useful in inventory control and monitoring, in warehouse flexibility, in last mile deliveries and in takeaways.

The drone package delivery market is projected to grow from USD 2.1 billion in 2023 to USD 27.4 billion by 2030, at a CAGR of 44.7% from 2022 to 2030[64] (Figure 29). Recent advancements in relevant technological fields such as VTOL[65] UpToDate mapping solutions and the rapid advance of IoT and Artificial Intelligence (AI) ecosystems are a contributory factor to the drone growth in the logistics sector.

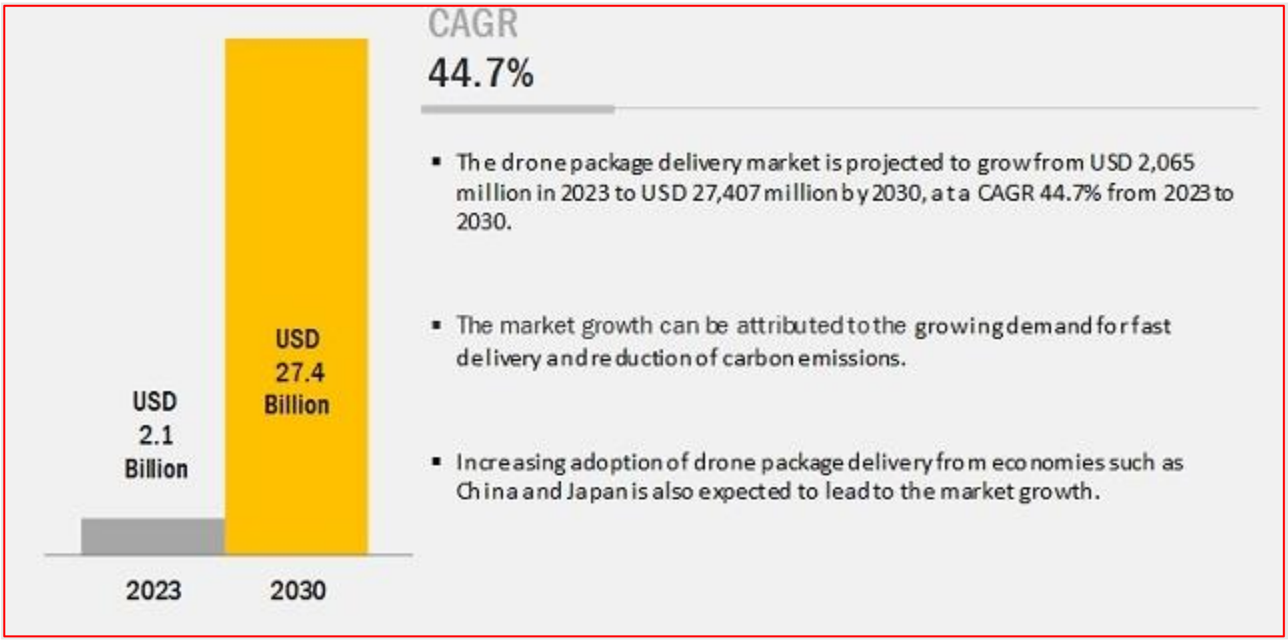

Figure 29 Drone CAGR projection for Deliveries/Logistics

2.2.1.3.2 Trends

- **Inventory control and monitoring**

With the rapid escalation of ecommerce, the need for a sustainable, cost-effective, and feasible solution to boost and supplement at first stage the human workforce and replace it, in a later stage is of utmost importance. The enhanced capabilities that a drone may offer such as connections over 5G network, real-time high-quality video and advanced tracking mechanisms give them the advantage in comparison to traditional inventory control and monitoring mechanisms.

[64] https://www.marketsandmarkets.com/Market-Reports/drone-package-delivery-market-10580366.html

[65] https://www.easa.europa.eu/light/topics/vertical-take-and-landing-vtol

At this point we have to consider that a warehouse is a very complicated and sophisticated environment that needs several mechanisms in collaboration with the human workforce to work simultaneously in order to have the expected outcome.

Figure 30 Drone using scanning solution[66]

In such a complex environment, drones are used to bridge any potential gap in the efficient management of an inventory. Scanning solutions, real time high-quality video, LiDAR techniques, QR codes and machine learning applications make the drones the most approachable solution (Figure 30). Estimates indicate that the warehouse drone-based solutions market will grow to $29 billion by 2027 at an annual growth rate of 20%[67]. The main objectives of using drones for inventory management are to increase the inventory accuracy, decrease labour costs, and minimize dangerous tasks for the workforce[68].

- **Warehouse Flexibility**

An additional sector in which drones can offer beneficial solutions is the so-called intralogistics. Intralogistics describes the internal material flow between the different "logistic hubs" - from the material flow in production, in goods distribution centres and in airports and seaports - as well as the related information flow[69]. In other words, drones are here to boost the communication and the transportation of goods between sectors and warehouses of the same enterprise. Apart from parcels and goods, intralogistics drones are here to support the human workforce by carrying tools, machinery and providing useful data. All these above-mentioned capabilities can not only save time, but they can also save energy. Real-time data, use of QR/bar codes and established sensors can significantly decrease the energy needed for the needs of a warehouse (Figure 31).

[66] https://roboticsandautomationnews.com/2019/06/28/inventory-management-using-drones/23992/

[67] https://www.whatnextglobal.com/post/drone-application-for-warehouse-inventory-management

[68] https://ethz.ch/content/dam/ethz/special-interest/mtec/pom-dam/documents/Drones%20in%20warehouse%20opeations_POM%20whitepaper%202019_Final.pdf

[69] https://www.logistics-journal.de/about/intralogistics

Figure 31 Warehouse Drones[70]

- **Drone Deliveries**

Drone deliveries may seem like a product of a science fiction film or of documentary film similar to those about flying cars. However, drone deliveries have faced a significant boost in the past few years. Over the past three years (up to 2021), there have been over 660,000 commercial drone deliveries to customers, not including the countless test flights to develop and prove the technology[71] (Figure 32).

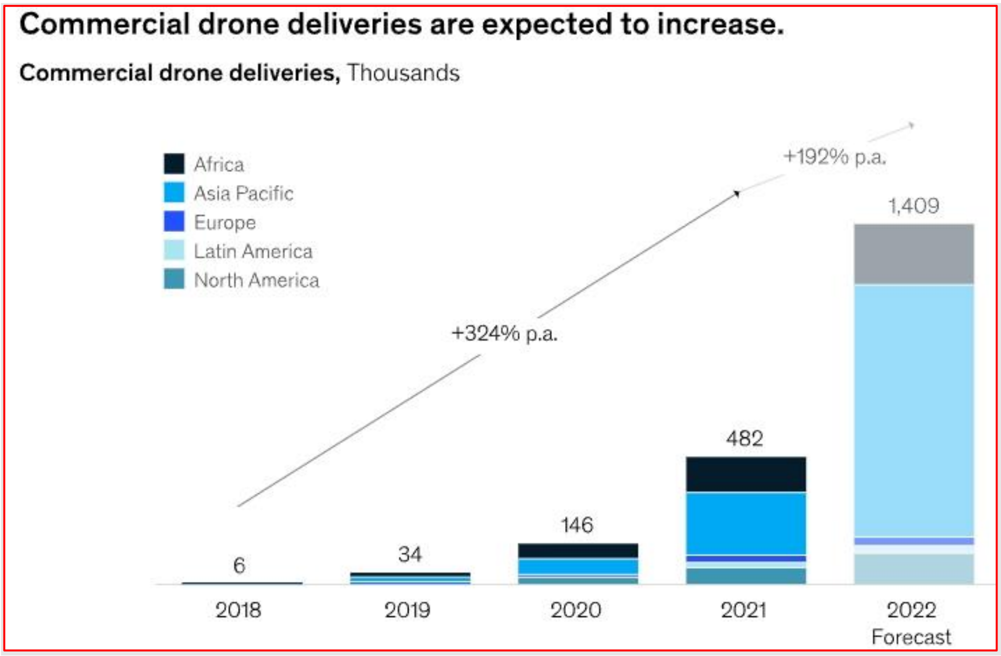

Figure 32 Commercial drone deliveries[72]

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[70] https://www.scmdojo.com/drones-in-warehousing/

[71] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/drone-delivery-more-lift-than-you-think

[72] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/drone-delivery-more-lift-than-you-think

Drone deliveries can cover a large variety of goods that can be delivered. From medical equipment, food and electronics. Almost everything that anyone can find to the traditional means of deliveries. Drone deliveries can offer enterprises lower costs that will lead to reduction of costs at the customer level. Drone deliveries can ensure a more efficient and reliable means of goods delivery which will consequently lead to higher rates of consumer trust. Furthermore, large companies' CEOs would more than happy to provide shareholders extra income from the cost saving drone policy[73]. Finally, drone deliveries are also an eco-friendlier solution that can reach rural and isolated areas and they constitute by far the quickest way to get the things in place.

Apart from drone deliveries as an independent feature, drones can be integrated in the last mile ecosystem. Briefly the last mile process is the last stage of the delivery process[74]. Generally, in a delivery process we have the following journey from warehouse shelf to the back of a truck, to the customer. The last mile term simply describes the procedure that a parcel follows just before reaching the customer. However, the last mile procedure is a bit problematic. This final stage of a product's journey may sometimes last for centuries and the real-time monitoring of the product may in some cases be unavailable. Drones at this point can offer the best solutions. Drones can precisely provide real data to deliver the product without causing troubles to the recipient with inaccurate data (Figure 33).

Figure 33 Last mile drone[75]

At this point it is worth mentioning that apart from the numerous drone deliveries capabilities there are some factors that may delay the mass use of drones in this field. The main problem here is the regulation context[76] which must set the exact guidelines about the BVLOS[77] flights (more details provided in Section 3 of this deliverable).

- Surveillance and Inspection Drones in Warehouses

As we have stated in previous chapters drones can be used for surveillance and inspection purposes in construction sights. The same applies for the warehouse. In warehouses, drones can be used for infrastructure inspections such as the roof, pallet placements, walls, and ceilings. Moreover, drones can be used in order to replace the human workforce in the surveillance of dangerous zones such as heights, where huge product piles are stuck or where extreme weather conditions are taking place.

[73] https://www.insiderintelligence.com/insights/drone-delivery-services/

[74] https://www.insiderintelligence.com/insights/last-mile-delivery-shipping-explained/

[75] https://www.globaltranz.com/transport-drones/

[76] https://www.ft.com/content/66487d88-a6b3-4e46-9b8a-00e38e93d3af

[77] https://www.geospatialworld.net/blogs/what-is-bvlos-and-why-is-it-important-for-drone-industry/

Drones can also be utilised for security purposes. Instead of using guides, drone with real-time monitoring capabilities can provide live feed to dedicated personnel[78]. But as we have already described, the rapid escalation of e-commerce leads the way to new more sophisticated and complicated warehouse operations in order to adapt to customer demands. Drone with their flexible shape can navigate through a warehouse, provide data information about the exact position of the products and retrieve missing packages (Figure 34).

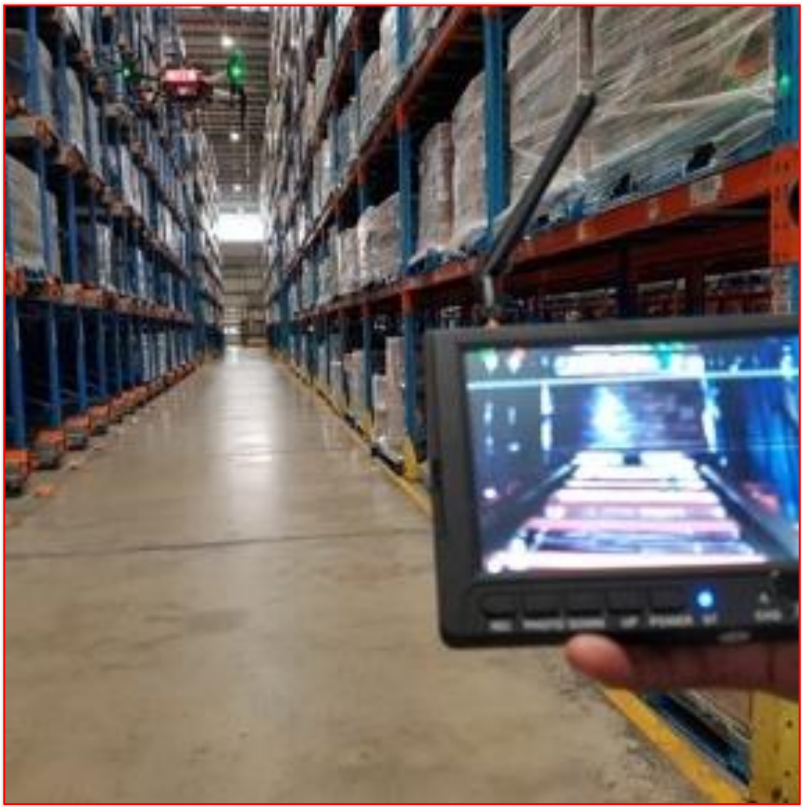

Figure 34 Drone Scan procedure[79]

2.2.1.4 Drone Taxis-Transportation

2.2.1.4.1 Market characteristics

Drones can be useful in transportations in various means. The first thing that comes to mind is drone taxis and in general drones which are used by people for their transportation purposes, whether they are completely autonomous or controlled by a pilot. However, drones can support traditional transportation means on several occasions. For instance, they can be used for inspection purposes in railways, to facilitate the traffic in roads or to transfer large cargo shipments.

2.2.1.4.2 Trends

[78] https://uavcoach.com/warehouse-drones/

[79] https://www.dronescan.co/research

- **Drone Taxis**

Recently, the first hub "Air-One mini-airport site"[80] for drone taxis has opened its gates in Coventry. This hub is open for demonstration flights of electric vertical take-off and landing (eVTOL)[81] and cargo drones. Many industries believe their vehicles will be safety certified and cleared for take-off by 2025, if not sooner. Boeing, Airbus and Hyundai are some of the familiar names building air taxis[82]. Recently, in South Korea they tested a traffic control system for drone taxis. An electric two-seater air taxi flew a short loop around Seoul's Gimpo Airport, while new technologies were used to successfully integrate it into the airport's existing traffic management system[83].

The costs for transporting passengers by drone are still highly uncertain. However, those developing the technology have suggested that it will be affordable to the wider population. In the longer run, they expect prices to become similar to those of normal taxis (for short trips) or high-speed rail or economy flights (at longer distance), or even below the costs of using your own car and viable for daily commuting. An analysis carried out for the US National Aeronautics and Space Administration (NASA) [84] estimated a passenger price per mile of USD 11 for a two-seater drone (comparable to current limousine-type services) and USD 6.25 for a five-seater drone (cheaper than limo services, but more expensive than luxury ride-sharing services) in the first years of operation (Figure 35).

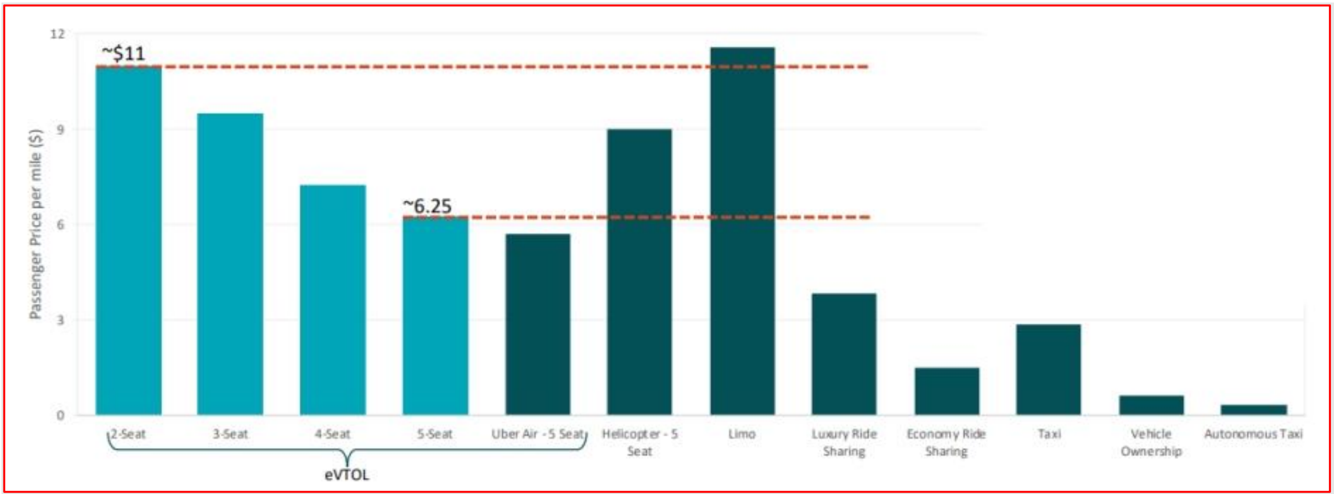

Figure 35 Price comparison of passenger drone services with other modes of transport[85]

- Inspection drones in railway stations etc.
- Drones for Traffic management
- Cargo Drones

[80] https://www.bbc.com/news/uk-england-coventry-warwickshire-61193195

[81] https://www.volocopter.com/newsroom/blog/blog-uamglossary-the-meaning-of-evtol/

[82] https://www.sciencefocus.com/future-technology/air-taxis-flying-cars/

[83] https://www.upi.com/Top_News/World-News/2021/11/11/drone-taxi-urban-air-mobility-flying-car/6821636646407/

[84] https://www.itf-oecd.org/sites/default/files/docs/take-off-integrating-drones-transport-system.pdf

[85] https://www.itf-oecd.org/sites/default/files/docs/take-off-integrating-drones-transport-system.pdf

It is important to note that by October 2022, no drone taxi model or flying vehicle has yet received certification from aviation authorities for the air transport of people, neither in the EU, the USA, nor in Asia.

The first formal showcase took place 20th of October 2022 in Dubai and was announced in press as per Apex World News, Dubai's first flying vehicle show took place The vehicle completed the unique operational risk assessment and received an initial special flying permission from the Dubai Civil Aviation Authority[86] (video also available in the footnote reference).

2.2.2 Governmental Areas

Drones are increasingly being used by government agencies over the last year. The most common applications under the governmental areas are the drones used by the police (patrol and surveillance), search and rescue, emergency response units such as pandemic relief. More details are provided in the following sections.

2.2.2.1 Police (Patrol and Surveillance)

As it may be completely natural, drones have also “invaded” several law enforcement authorities, such as the police. Police uses drones for several reasons such as the surveillance of a city, chasing of suspects, crime scene investigation and for the management and control of large events.

2.2.2.1.1 Market characteristics

Current trends have already shown a strong uptake from police in the patrol and surveillance verticals. Table 1 indicates the drone usage in the UK by these departments and insinuates the majority of departments are already using them for “Aerial Searches, including missing persons”, “Road Traffic Collisions”, and “Crime Scene investigations”.

Table 1 Patrol and Surveillance vertical uptaken by police

	Protests and Public order events	Anti-Social Behaviour	Fire incidents	Command & Control of Operations	Road Traffic Collision	Firearm Support	Aerial Searches (inc. missing person)	COVID	Public Events	Thermal flyovers	Training and Demonstrations	Crime Scene Investigation
Avon and Somerset					X	X	X		X		X	X
Bedfordshire Police					X		X					X
British Transport Police							X					X
Cleveland Police	X	X			X		X					X
Cumbria Constabulary				X		X	X				X	
Total	12	8	7	12	18	8	32	4	10	6	13	21
% of those providing details	37%	25%	22%	37%	56%	25%	100%	12%	31%	19%	41%	66%

[86] https://nitter.it/apexworldnews/status/1583010172435251200

On a global scale, the law enforcement drone market is set to increase from $500m in 2020 to $2.8bn in 2030 (Figure 36), indicating a growth in the number of drones used, the implementation of additional drone software services, and an expansion in the potential use cases.

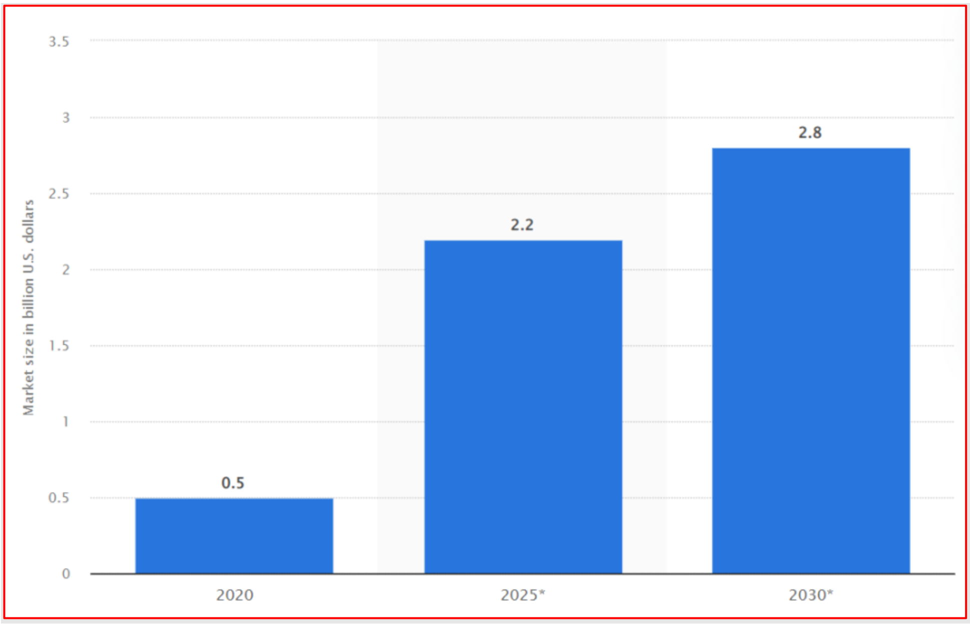

Figure 36 Law Enforcement market increase

2.2.2.1.2 Trends

- **City Surveillance**

Most of the time the surveillance process or mapping procedure of a crowded city is not an easy task for the local authorities, especially when we are considering cities with high traffic flow. Drones are not only applicable to monitor a city when everything is fine or when the biggest problem is the traffic jam but also when extreme weather conditions or natural disasters are taking place, or even before as a precautionary mean.

Drones in general, can be more accessible and easily utilised in order to intervene in case of a natural disaster or of an unexpected event in a city. Also, drones can access places which are not accessible by people or by other types of vehicles, such as cars or helicopters. The constant development of mobile networks such as 5G gives the opportunity to drones to provide high-definition live feed from the incident scene to all the interested parties. As it may be easily concluded at this point drones can play a contributory factor to the smart-city[87] transition (Figure 37).

[87] https://www.techtarget.com/iotagenda/definition/smart-city

Figure 37 Drones over a smart city[88]

- **Chasing suspects and Crime scene Investigation**

Chasing a suspect is undoubtedly not an easy task for all police departments around the world. At this difficult and at the same time risky procedure drones emerge to provide a more efficient, safer and quicker way for reaching the suspects. A suspect can move from one place to the other confusing any engaged ground forces. So, drones may assist ground forces by providing useful intelligence about the condition of the suspect. Also on a pursuit, a drone is much more quitter[89] than a helicopter and a more efficient means to provide the live status of the suspect. Also, the image of the moving suspect along with the prevailing location can give a new perspective to the engaged forces to decide about the way they are going to act and find the best and safest solution. Similarly, the crime scene investigation was initially based on traditional means, so drones may also come at such occasions to provide a new perspective a more detailed picture, from a wider angle and at different heights[90].

2.2.2.2 Rescue

2.2.2.2.1 Market characteristics

Drones and UAVs in general are able to provide a unique variety of applications in search and rescue (SAR) operations. Such operations include emergency and security missions and in general when humanity faces serious problems or dangers. Drones can be fast, can more easily communicate with damaged or dangerous place, can access remote areas, and are cheaper and safer than a traditional mean of search and rescue (e.g. helicopter) [91].

[88] https://singularityhub.com/2020/07/08/how-drones-and-aerial-vehicles-could-change-cities/

[89] https://www.forbes.com/sites/stephenrice1/2019/10/07/10-ways-that-police-use-drones-to-protect-and-serve/?sh=7ea1714b6580

[90] https://consortiq.com/uas-resources/how-drones-improve-crime-scene-investigation

[91] https://flytnow.com/drones-for-search-rescue/

2.2.2.2.2 Trends

- **Inaccessible Terrains**

In the drone's history anyone can find examples when drones gave access or information about incidents where access was almost impossible. Drones do not only have the capability to spot and provide a clear view of a place in danger but also to help people or animals in danger. Drone can easily go to remote areas where access is not easy or infeasible and provide help to trapped people. One characteristic example is the rescue of a mother and a daughter back in 2018 in Lake Whitney[92] in the USA when a drone provided them with life jackets saving their lives (Figure 38). At this example a drone provided them a solution when and where responders couldn't utilize boats to provide assistance in a very tight time-frame where each second counts.

Figure 38 A drone carrying lifejackets

Apart from this example, drones are more often sent to spot and save hikers when they face disorientation issues or get lost[93]. In recent days more and more fire departments utilize drones as a valuable assistant. Drones are reaching areas where the human factor has not the capacity to easily overcome. According to DJI manufacturer and their mapping procedures it is counted that until early 2021 more than 500 people have been saved by drones[94].

- **Situation Awareness**

Situation awareness allows one to have a descriptive overview of the current state of a situation due to an incident, as quickly as possible to respond in the best possible way.

When the incident occurs, the forces involved must be able to benefit from as much information as possible in order to give the most effective response. The better the situation is perceived and understood, the better the effectiveness of these teams. The increasingly high performance of cameras, sensors and communication networks is already improving the situation, but public safety teams could

[92] https://flymotionus.com/2022/03/09/how-drones-save-lives/

[93] https://uavcoach.com/search-and-rescue-drones/

[94] https://dronelife.com/2020/12/01/more-than-500-lives-saved-by-drones-dji-continues-mapping-project/

be helped in the analysis of this quantity of data thanks to innovative tools which will allow them to ingest dozens of data sources and to give the right instructions in a very short time.

On the one hand, drones bring the possibility of easily and quickly obtaining an overall and precise view of the situation when the rescue teams cannot access certain areas, which is often the case during a natural (earthquake for example) or human (terrorist act for example) disaster. On the other hand, 5G networks make it possible to obtain very high communication performance, both in terms of latency and throughput. These two characteristics of 5G allow efficient control of drones and the gathering of information in near real time with great precision (more details provided in Chapter 4 of this deliverable).

When a drone is available sometimes there is no meaning in utilizing other means for providing a view of an incident or a remote area. UAVs can provide real-time visual information and data[95] before, during or after an incident. Drones equipped with up-to-date sensors, cameras and equipment can provide real-time footage and help all the involved partners to take the best available choice (Figure 39). Such drones can not only identify objects or people from above but also shed light to areas where visibility is limited and provide detection operations by thermal signatures. Also, the enhanced cameras with optical zoom can zoom into the incident's place and provide the best possible image in order to help the rescue team to assess and evaluate the situation in the best post possible way.

Figure 39 Drone in situation awareness mission[96]

- **Direct Communication**

Besides, the above-mentioned attributes of drones can offer direct communication between the rescue team and the trapped people. Onboard speakers and microphones along with cameras bridge the gap of communication between someone in need and the drone which represents the rescue team. Through this communication process the rescue team can assess each situation in the best possible way and deploy the most suitable responders' team. Basic visual indicators enhanced with flight patterns for drone-human interaction and human signalling based on aircraft marshalling for humane-drone interaction might facilitate the process and provide efficient communication (Figure 40). The most important aspect of this communication attribute is that such a drone may provide navigation directions to trapped people, limiting the risk of sending a rescue team. Especially in the context of 5G,

[95] https://www.airbornedrones.co/search-and-rescue/

[96] https://www.securitysystems.in.th/2022/02/cruising-altitude-how-drones-with-data-elevate-industries-en/

communication drones can provide reliable and stable communication between the involved partners without interruption of signal in remote areas.

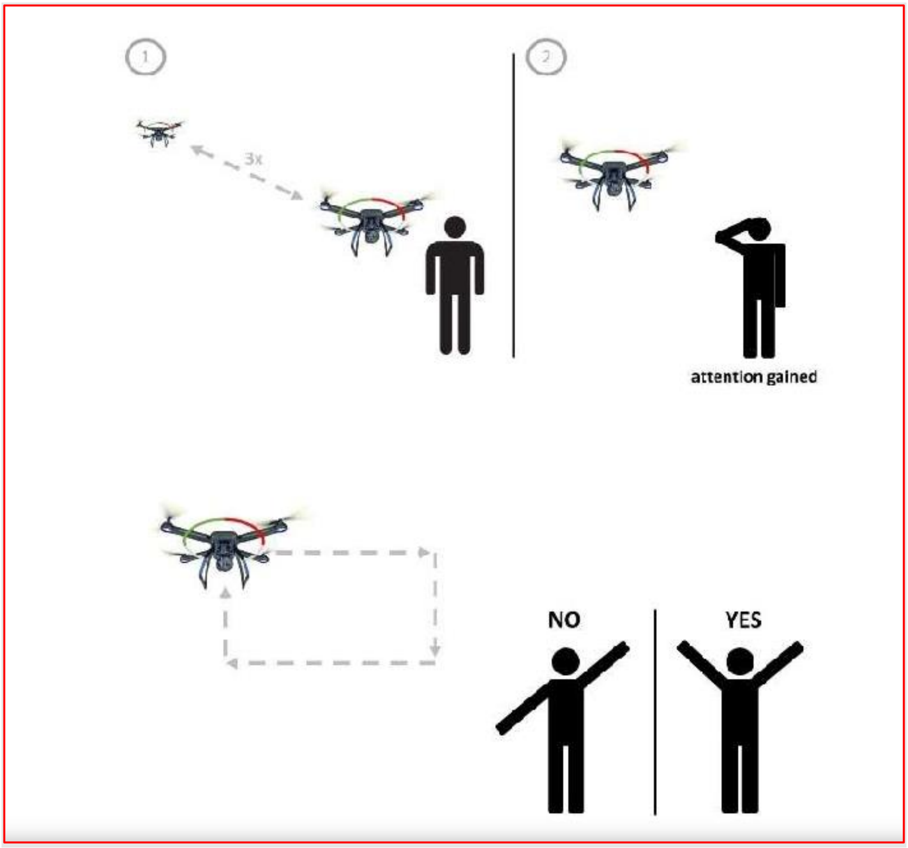

Figure 40 Human interaction with drone[97]

- **Safer and Cheaper mean of rescue**

Drones are, in principle, the cheapest and at the same time safest means for rescue purposes. Drones do not put human resources in danger for search and rescue purposes, unless it is absolutely necessary. Furthermore, it is a cheap means of rescue, because no large equipment or other aerial means are required to provide their services (Figure 41).

Also over the last year, several EU regulations/updates have been released since February 2018, when the European Aviation Safety Agency (EASA) published the first formal proposal to regulate the safe operations of small civil drones in Europe[98].

[97] https://www.semanticscholar.org/paper/Conceptual-Design-of-Human-Drone-Communication-in-Doran-Reif/4147a9135d52fd2914743989210b37d96c30bd44

[98] https://www.internationalairportreview.com/article/71710/safe-operation-drones-europe/

Figure 41 Flying drone – Special small camera equipped for rescue missions[99]

2.2.2.3 Drones against Pandemic Diseases

2.2.2.3.1 Market characteristics

One of the subjects that have put the world in severe danger in the last two years is the COVID-19 pandemic. Since early 2020, the whole world is facing on a daily basis the effects of the COVID virus. Effects that do not only put at risk the health and safety of people but affect their everyday lives in an indirect way as it limits their lives in a much broader way.

Since the first days of the pandemic scientists and researchers have tried to find a way to combat and tackle issues related to coronavirus. A means that was extensively used to help in this situation was drones. Drones used by the authorities to control the distances' maintenance among entities, for medical deliveries, supply, patient detection and aerial spraying. Drones in COVID-19 pandemic is a typical example of how drones can be used in new sectors and areas, with new missions and scope, in order to tackle equivalent situations in the future.

2.2.2.3.2 Trends

- **Aerial Surveillance – Distance keeping**

One of the factors that causes the hyper-contagion of this virus is the ease in which virus particles transmit from one person to another. The virus can be transmitted through particles from saliva, cough and speech. As it can be clearly understood, human interaction in the COVID-19 era was extremely risky, especially in the beginning of the pandemic when vaccines and related medicines were not available. So, authorities had to find a way to control and restrict people from mass gatherings. The best way for tackling this issue is a drone. Autonomous or semi-autonomous drones using cameras can give a topographic image of each location giving access to related authorities to take actions and protect citizens. Drones can also be programmed to perform scheduled routes[100] in order to have the clearest

[99] https://www.internationalairportreview.com/article/71710/safe-operation-drones-europe/

[100] https://www.mdpi.com/2504-446X/6/3/59/htm

picture of each location 24 hours a day. Furthermore, drones can carry large speakers for providing instruction to citizens or even scolding[101] them when they put public safety in danger (Figure 42).

Figure 42 Drone Controlling the crowd during COVID-19[102]

- **Medical Deliveries Supply**

The most important thing in a pandemic outburst apart from the humans is the availability of medical goods and medicines. Medical supplies that had not only be transported to big cities and towns but also to remote areas[103] and underdeveloped countries such as the Sub-Saharan African countries[104]. Apart from remote areas, drone medical deliveries are extremely useful for people who are sick and the elderly ones who may not have the capability to go to the pharmacy or to the hospital for help. Medical supplies such as vaccines, medicines, testing samples can be easily transported from hospitals and health centres to remote areas and testing centres, in an easy and seamless way, delivering directly only to authorised areas and personnel, keeping unauthorised people away (Figure 43). Drones in this situation are not only a means for keeping the distances but also a very useful means for doing things in less time (this footnote reference link shows 5 hospitals that have enabled a drone program for the combat against COVID-19[105]).

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[101] https://theconversation.com/pandemic-drones-useful-for-enforcing-social-distancing-or-for-creating-a-police-state-134667

[102] https://www.dw.com/en/german-police-mull-wide-use-of-drones-for-corona-surveillance/a-53085401

[103] https://reader.elsevier.com/reader/sd/pii/S0967070X21000779?token=04D5BCD79077DAFF181A163F6892E7F96FB7201599DFFE38E839D3070C6F15ACA84D24E944033D132B2BDA52165B5A54&originRegion=eu-west-1&originCreation=20220812112857

[104] https://www.unicef.org/supply/media/5286/file/%20Rapid-guidance-how-can-drones-help-in-COVID-19-response.pdf.pdf

[105] https://www.beckershospitalreview.com/digital-transformation/5-hospitals-using-drones-to-deliver-covid-19-supplies.html

Figure 43 Drone carrying medical supplies

- **Patient Detection**

Another application of drones used in pandemic situations is the patient's detection and temperature measurement. Drones using thermal cameras can easily spot people who face symptoms in public areas and immediately isolate them in order to reduce the further spread of the infection (Figure 44). Of course, thermal cameras have been used in the past for several reasons, however in such situations we realise how they can protect public safety from infections spread in a new monitoring way. So, the objective of such missions is not only to control large areas in order to keep people away from gatherings/congestions in such areas, but also to spot the ones who face symptoms and isolate them or to inform the ones who are not aware that they may suffer from symptoms over the next days since they interact with COVID-19 positive people.

Figure 44 Drones using thermal cameras to detect patients[106] [107]

- **Aerial Spraying**

Usually, drones are being used for spraying agricultural areas. But since COVID-19 came to surface, spraying drones have been utilised in order to help the fight against the virus. Apart from human interaction COVID-19 can be transmitted also by contaminated surfaces. Spraying drones can be used for disinfecting contaminated areas where lots of cases have been identified but also vehicles that need

[106] https://english.alarabiya.net/life-style/healthy-living/2020/03/29/Coronavirus-Thermal-drones-monitor-body-temperatures-in-Saudi-Arabia-s-Qassim

[107] https://www.biometricupdate.com/202004/pandemic-drone-tests-to-monitor-for-covid-19-infections-ends-quickly-due-to-privacy-concerns

to travel from a contaminated area to a "clear" one (Figure 45). "Drone spray can be fifty times more efficient than people spraying"[108]. So aerial spraying can play a key role in the prevention of a virus spread. However, at such an activity several authorities must collaborate in order to ensure public safety.

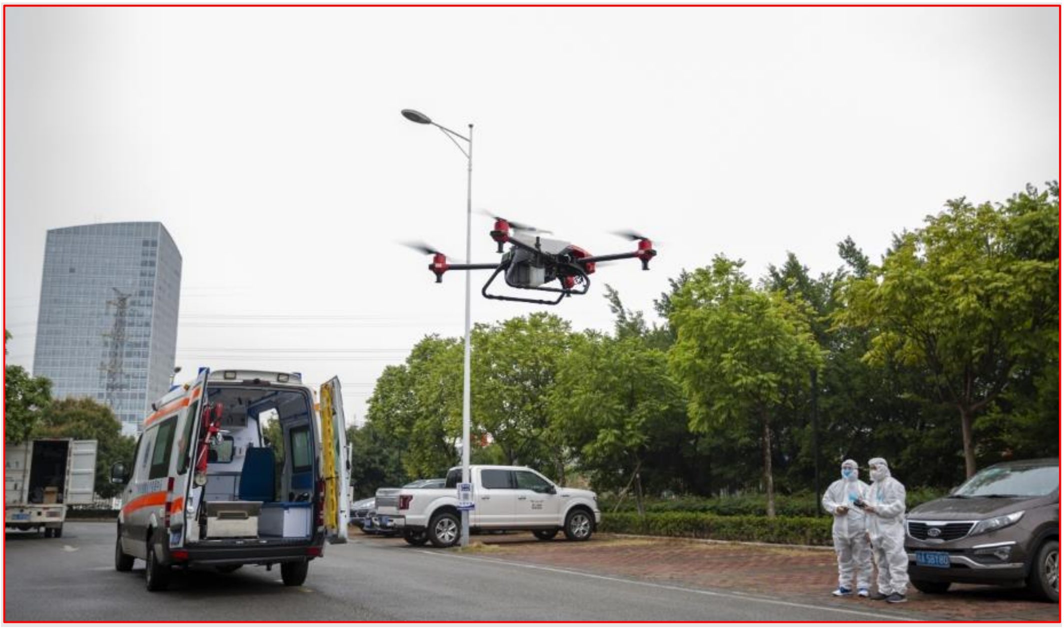

Figure 45 Spraying Drone against COVID-19[109]

2.2.2.4 Integrated Public Safety Control Room

2.2.2.4.1 Market Characteristics

Public Safety organizations are inherently searching ways to optimize their operations. UAVs offer unique opportunities to provide additional information and improve the operational picture in a quick and safe way.

To enable safe and secure drone operations, the authorization and approval process with stakeholders of the airspace (e.g. ANSPs, military, other governmental organizations) needs to be automated as much as possible – this means that an integrated public safety control rooms needs to make use of machine-to-machine interfaces on all sides.

All involved stakeholders have a big focus on safety as well as secure communications – but still there is a big need to enhance their workflows and improve coordination.

2.2.2.4.2 Trends

The Figure 46 PS Control Room Integration, shows a schematic architecture of an integration between public safety officers in need of additional aerial information – the public safety control room who is requesting and coordinating the missions – UAV operators who actually fly and provide data – and the

[108] https://www.weforum.org/agenda/2020/03/three-ways-china-is-using-drones-to-fight-coronavirus/

[109] https://www.weforum.org/agenda/2020/03/three-ways-china-is-using-drones-to-fight-coronavirus/

approving authorities. This integration shows the need of safe and secure machine to machine interfaces between different stakeholders to fulfil the actual need of the end-user.

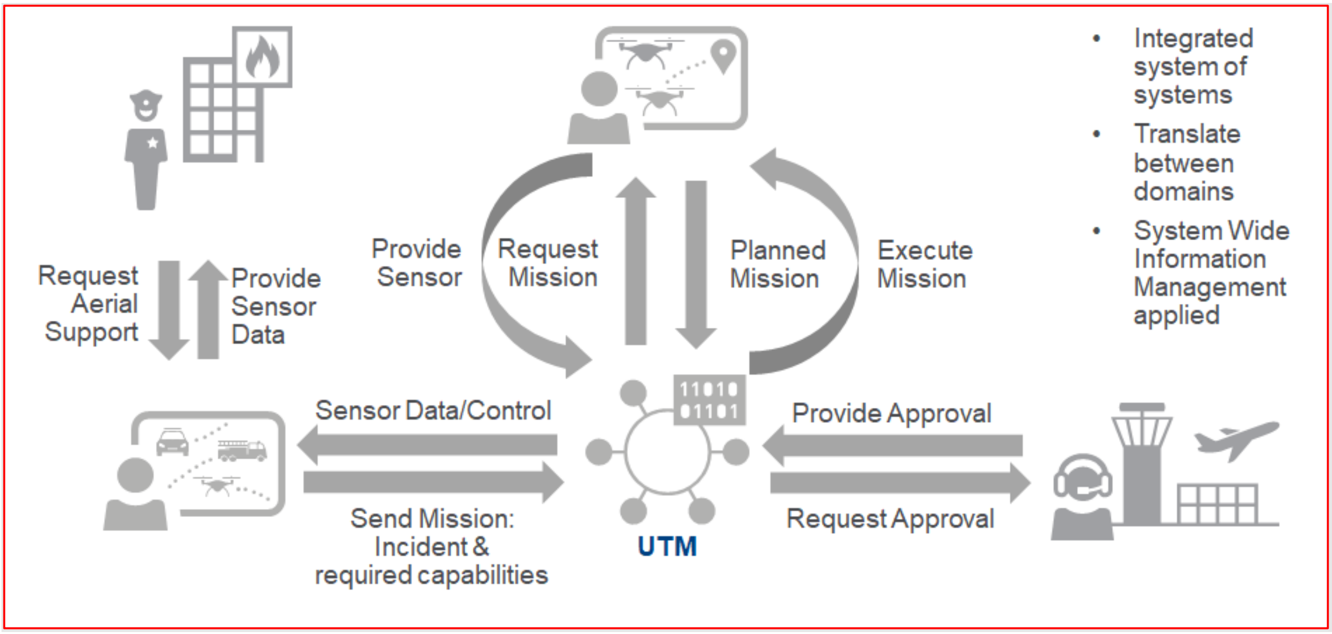

Figure 46 PS Control Room Integration

2.2.3 5G!Drones Use Case Areas: Market Details and Trends

The main aim of the 5G!Drones project involved executing UAV vertical use cases on top of 5G facilities. Other objectives included 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 (aspects analysed in WP4 and presented in WP4 deliverables).

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 market details and trends of the four 5G!Drones use cases, which were implemented and tested using the 5G facilities of four platforms, are presented and analysed in the next sections.

2.2.3.1 5G!Drones UC1 - UAV Traffic Management

The strong growth in drone traffic and the according EU regulations are a major challenge for the involved stakeholders. Main goal of UTM is to integrate all airspace related data to allow safe, secure, and fair operations for unmanned and manned air traffic all over European airspaces. In addition, the involvement of different U-space service providers to create a business value chain of all stakeholders is needed. Figure 47 U-space implementation roadmap presents the planned U-space implementation roadmap[110].

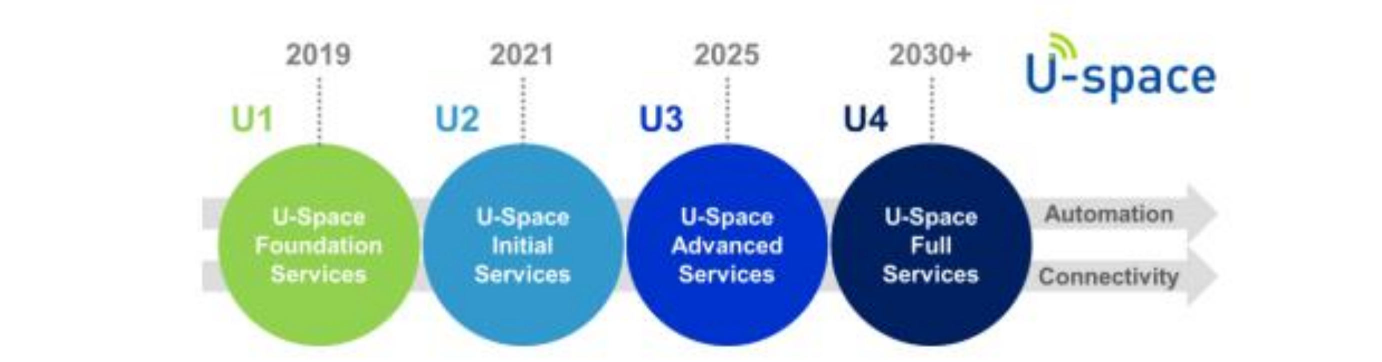

Figure 47 U-space implementation roadmap

Especially the upcoming regulation package to be implemented from 26th January 2023 drives a lot of activity from different stakeholders all over Europe. Despite the given date for U-Space regulation entering into force in the European Union, only two nationwide UTM projects were launched in the first half of 2022. This is probably due to several factors: Covid pandemic, the regulation ambiguities, which have to be revised and lack of clarity on the business case for UTM service providers.

Today, there are mainly ANSPs working on programs and implementations to follow these developments (see the status per country below). This is a tedious effort, setting up the base for other, local players. It is expected that from 2024, the main weight of UTM implementation will shift from ANSPs towards cities and ports, which will become the major market drivers. Importantly, the BVLOS drone flights will be the key factors for market growth.

Year 2024 is expected to be a turning point for the UTM industry, when the regulations, standardization and technology readiness level will be ready for the commercial, automated BVLOS in some European countries. Below paragraphs, provide an update of the current status in specific countries of interest for 5G!Drones partners of UC1.

- **Austria[111]**

The new UTM drone traffic management system is paving the way for an ecosystem that meets the increasing demand for drone flights in a regulated airspace, thanks to the possibility to embed a wide range of services and the connection of additional user groups, such as blue light organisations

The most important features and services that will be implemented gradually over the next few years are:

- The intuitive application for air traffic controllers and the mobile application for drone pilots enabling the real-time
- establishment of airspace rules and restrictions,
- review of flight plans, and
- issue clearances for drone pilots.

[110] https://www.researchgate.net/publication/351174535_Unmanned_Aerial_Traffic_Management_System_Architecture_for_U-Space_In-Flight_Services

[111] https://www.austrocontrol.at/en/company/media/press__news/detail/__65

- Warnings of airspaces that are closed - even at short notice.
- Digitisation of the previously manual approval of flights and thus a vast improvement in services for drone pilots.
- The traffic management system for drones also supports the Austrian economy, which wishes to establish new services on the market through the use of drones.

The system is expected to be operational early 2023.

- **Switzerland**

The Federal Office of Civil Aviation (FOCA), as the body responsible for development and supervision of civil aviation in Switzerland, is mandated to integrate the UAV traffic. As the U-space regulation is expected by January 2023, FOCA has the ambition to have it applicable in Switzerland already in April 2023.

April 2023 seems to be the month, where also other parallel initiatives from FOCA will converge. FOCA opened the certification of USSP (U-space service providers) a few months ago. The target would be to have the first certified USSP in Switzerland by that date as well. Last but not least, Switzerland is also looking to create the first U-space airspace of Switzerland (and most probably of Europe) in the Zurich area, where most of the commercial drone operations in Switzerland are concentrated today. The time horizon for the activation of this airspace would be April 2023.

- **Poland**

Polish ANSP, PAŻP (Polska Agencja Żeglugi Powietrznej), was the first ANSP in the world, that back in 2020 launched commercially fully operational UTM system (PansaUTM platform) to coordinate UAS flights all over the country. During 2020 system was, after thorough tests and certifications (becoming the first and the only one system certified in the world), rolled out in all ATC towers in Poland: Bydgoszcz, Gdańsk, Katowice, Kraków, Lublin, Łódź, Modlin, Olsztyn, Poznan, Rzeszów, Szczecin, Wrocław and Zielona Góra. It is used by ATC to:

- Monitor the UAS traffic (based on e-identification and telemetry)
- Receive and accept/reject flight requests (including information about pilots and their certificates)
- Receive flight plans
- Geo-fencing
- Maintain direct communication with UAS operator through CDDLC (Controller-Drone Data Link Communication)

The system is integrated with mobile application used by drones' operators to plan missions, request flight permissions, communicate with ATC[112].

PansaUTM system provides all required U1-U4 services, according to current standardization. It is currently used by ANSP, but its modular architecture allows the deployment of this platform for U-space management by other USSPs (e.g. LAUs). The PansaUTM system was awarded with 2020 the ATM Excellence Award.

[112] www.droneradar.eu

- **Estonia[113]**

Estonian Air Navigation Services (EANS) is currently implementing an environment where drones and civil aviation can coexist in the shared airspace. By integrating air traffic management (ATM) and unmanned traffic management (UTM) on the same platform, situational awareness and safety will be enhanced, allowing increased use of drones in Estonia. The project will accelerate the roll out of Estonian U-space and allow drones to serve critical industry.

The system is expected to be operational at the end of 2023.

2.2.3.2 5G!Drones UC2-Public Safety

The market for public safety drones, including hardware and associated flight management and control systems, is approximately $1.15 billion[114] in 2022. It is becoming more accessible for relevant departments thanks to a wider variety of hardware (examples could include light-weight drone-compatible thermal imaging, such as the DJI Zenmuse H20T[115]), and more advanced software for the command and control of drones.

Drones are real assets in public safety, with uses including security, firefighting, search and rescue, and other rapid situational responses. They can provide similar aerial viewpoints as helicopters but with a faster response time, significantly cheaper cost to run, and without endangering the pilots. The development of flight-capable software and 5G capabilities is introducing a layer of autonomy to drive efficiency and further reduce response times, making drones ever more useful in the public space.

- **Wildfire Mitigation**

Current responses to fires in forested or agricultural environments rely on the slow mobilisation of planes, and communication between responders to locate the source of the fires is fragmented. There is a short timeframe in which fires can be suppressed effectively.

Drones can help gather situational awareness, protect firefighters, and enable mapping for both pre-emptive and proactive responses. 97–99% of all wildland fires have been successfully suppressed during initial attack[116], evidencing the importance of mitigation and early drone imaging.

Rescue solutions for global emergencies may also endanger the lives of first responders, and drones create an efficient support tool for first responders, reducing the risk of serious injury. The capacity and reliability of 5G means videos can be streamed from the drones to several responders, increasing the coverage, transparency, and situational awareness of responders in fire-scenarios. Thermal cameras add to the awareness by recognising the source of the fires, to mitigate further breakouts.

- **Law Enforcement and Surveillance for Public Safety**

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[113] https://www.frequentis.com/sites/default/files/pr/2021-03/20210329-pr-frequentis-eans-utm.pdf

[114] https://www.researchandmarkets.com/reports/4031505/worldwide-public-safety-drones-market-by

[115] https://www.heliguy.com/products/zenmuse-h20t-thermal-camera

[116] https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.431.4389&rep=rep1&type=pdf

Traditional surveillance methods have the disadvantage of fixed angles, limited range, and costly setups, and the failure to detect security risks can lead to expensive consequences.

In public areas, drones providing real-time high-resolution video can ensure awareness to officers for breaking situations, and swift action can then be taken, ensuring no consequences to the site of interest. Drones can be used as a tool to respond to an individual incident, or consistently in order to ensure the safety of an area in an extended period of time. These drones are cheaper than helicopters and manual policing solutions, and reduce the time spent for law enforcement in menial work.

2.2.3.3 5G!Drones UC3-Situational Awareness

Situation awareness operations include all missions where a perception of elements in a desired environment is needed. This includes a wide variety of fields from inspection to environmental monitoring. The market of inspection and monitoring is growing and is expected to be valued from $6.44 billion in 2020 to reach $35.11 billion by 2035[117].

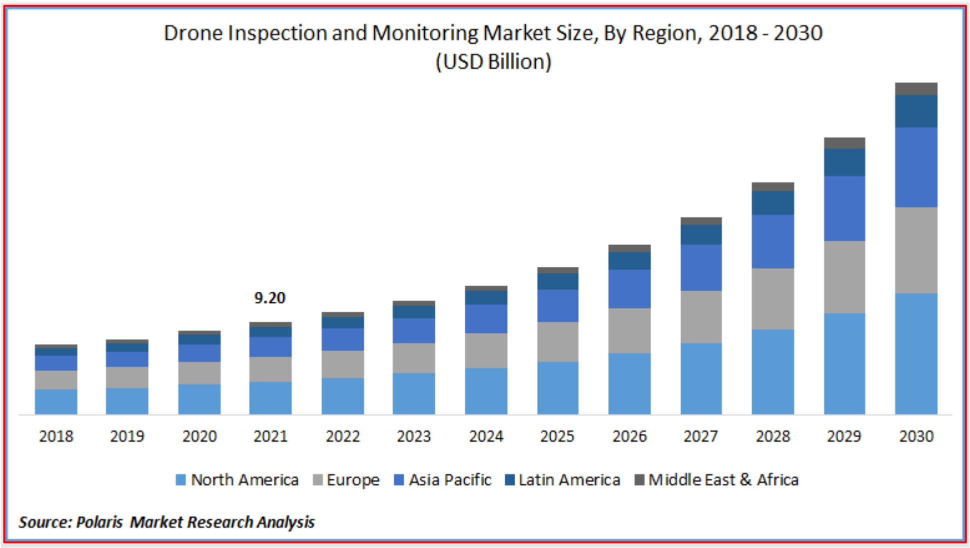

Figure 48: Market evolution for drone inspection and monitoring by regions

Companies are looking for solutions to inspect their facilities, and monitor their events in a cheaper, faster way, but also provide new data to provide a better understanding of a situation. Drones, by their size and price, but also by the fact that they are unmanned give an interesting tool for these organisations to meet their goals. Drones can provide a bird's-eye view to inspect elements close to infrastructure, which would require a heavy logistic otherwise, or allow monitoring environmental elements in a more precise and accurate manner than being performed today. This helps understand the evolution of the environment caused by climate change, and the understanding of the situation as well as helping for the decision-making process thanks to the elements provided by this technology. Drones are being more and more used as they are becoming more accessible by all the interested organisations.

Situation awareness allows one to have a descriptive overview of the current state of a situation due to an incident, as quickly as possible in order to respond in the best possible way.

[117] https://www.alliedmarketresearch.com/drone-inspection-and-monitoring-market-A14422

When the incident occurs, the forces involved must be able to benefit from as much information as possible in order to give the most effective response. The better the situation is perceived and understood, the better the effectiveness of these teams. The increasingly high performance of cameras, sensors and communication networks is already improving the situation, but intervention teams could be helped in the analysis of this quantity of data thanks to innovative tools which will allow them to ingest dozens of data sources and to give the right instructions in a very short time.

On the one hand, drones bring the possibility of easily and quickly obtaining an overall and precise view of the situation when the rescue teams cannot access certain areas, which is often the case during a natural (earthquake for example) or human (terrorist act for example) disaster. On the other hand, 5G networks make it possible to obtain very high communication performance, both in terms of latency and throughput. These two characteristics of 5G allow efficient control of drones and the gathering of information in near real time with great precision.

The areas in which situation awareness is gaining momentum are diverse. We can cite industry, aerospace, and defence. Thus, in the latter area for example, security and border surveillance are improved, with more data and more quickly, while guaranteeing the safety of operators who can proceed remotely but in real time. Thus, the market for drones in the field of situational awareness is growing rapidly. According to a report from Globe News Wire[118], the size of this market will increase with a CAGR of 45%.

2.2.3.4 5G!Drones UC-4 Connectivity during Crowded Events

Drones can be useful in several, separate use cases involving crowded events, from monitoring and analysis for safety and security viewpoints to connectivity extension / providing wireless coverage to an extensive number of users.

- **Crowd Monitoring and Analysis**

  Existing monitoring tools, such as CCTV, are constrained by tight angles and limited range. These limitations can mean blind spots, false callouts, and an increase in malicious activities due to the predictability of fixed infrastructure.

  In public areas, drones providing real-time high-resolution video can ensure awareness to officers for breaking situations, and swift action can then be taken, ensuring no injuries in the crowd. Drones can be used as a tool to respond to an individual incident, or consistently in order to ensure the safety of an area in an extended period of time. These drones are cheaper than helicopters and manual policing solutions, and reduce the time spent for law enforcement in menial or dangerous work.

- **Connectivity Extension**

  Networks are often at capacity during crowded events, resulting in slower transfer speeds.

One mitigation strategy is the placement of UAVs as aerial base stations to provide wireless coverage for users in a specific event that may be throttled by this network capacity. Not only are these flexible to deploy, but swarms of drones may be used as a method to scale this extension for larger crowds. It can be as simple as adding an additional payload to a drone, and can be further enhanced through automatic charging

118 https://www.globenewswire.com/news-release/2022/08/26/2505277/0/en/Tethered-Drone-Market-Forecast-to-2028-COVID-19-Impact-and-Global-Analysis-By-Type-Application-and-End-User.html

It is absurd to keep gNBs and relaying equipment solely static as networks and UEs become more mobile, especially for providing coverage, for example, in hotspots and in areas with subpar infrastructure (such as rural and suburban areas that suffer from a lack of financial incentives for network operators, disaster recovery environments, and rural and suburban areas that are underdeveloped). Some significant advantages of airborne communication BSs over conventional static GBSs that are published at fixed locations are the following:

- airborne communication BSs may be hastily deployed in response to demand, such as brief or unforeseen events.
- Due to their great altitude above the ground, airborne communication BSs are more likely to have line-of-sight (LoS) connections with their ground users, offering better QoS.
- Because of their additional degree of freedom (DoF), UAVBSs may modify their locations in 3D, which improves communication performance in an agile way depending on the circumstances.

From a market perspective, Google made the first significant industry effort, attempting to solve the lack of infrastructure to provide connectivity for under-served areas. Project Loon sought to use stratosphere balloons to bring connectivity to isolated or rural locations. These balloons would float at a height of about 20 kilometres. The fundamental concept was creating a stratosphere-layer mobile ad hoc network and guiding the balloon to the location in need of coverage using wind waves moving in the appropriate direction[119].

However, due to significant operating costs, this concept was abandoned since it was unworkable from a business standpoint. Each balloon's material composition was assigned an initial cost estimate of $17,870. The entire cost of the balloons must be passed along to the customer if the project is to be completed without incurring a loss for Google. This zero-deficit requirement's cost to customers is calculated using a payback period plot (Figure 49). This repayment period plot is intended to determine the unknown quantity of the cost to customers over a five-year period as opposed to a typical payback period plot, which compares two known quantities. This is discovered by adjusting the line's gradient so that its junction happens after five years. The gradient may be used to calculate the cost for each group of customers every day because each balloon has an ongoing cost of $40,318 over the course of five years.

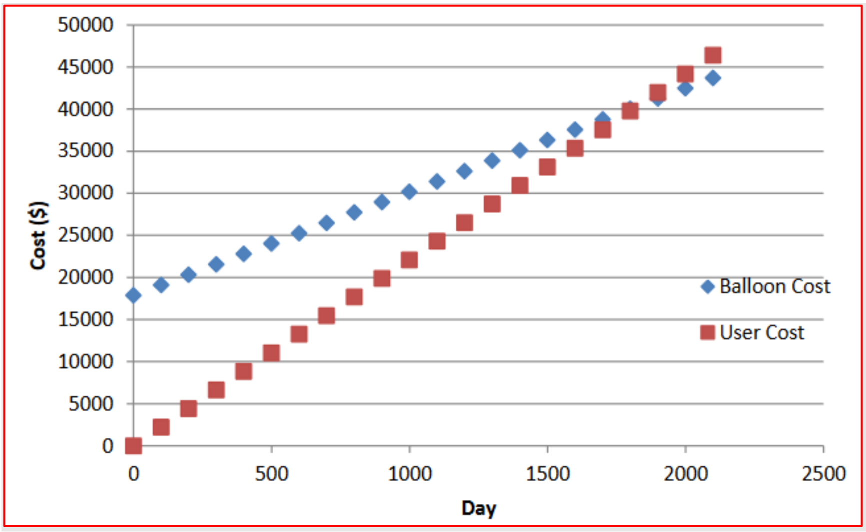

Figure 49 Pay-back period for cost parity

[119] https://www.datacenterdynamics.com/en/analysis/connecting-world-balloon/

Considering that the total cost per balloon over a five-year period was calculated to be $40,318[120], for two divert scenarios in terms of total market size and population density, that of Australia and this of India, it is estimated that assuming a 5% user adoption rate, each client would have to pay between $833.19 and $1.86 for the two scenarios under consideration to operate at no cost to Google. In the extreme scenario of 100% user adoption rate, each client would have to pay between $0.023 and $0.000051. Thus, the biggest hurdle for Project Loon is that monetizing it will make it less appealing for use, since areas which are in greater need of access are occupied by poorer people. This implies that Project Loon is inherently unprofitable as charging for access will drive away the core user base.

Similar to that, a significant amount of research has been done recently on the topic of providing broadband through satellite. But satellite-enabled NR channels are not suitable for real-time or mobile applications due to a number of serious restrictions. Aside from software and hardware solutions, specialised receivers and demodulation devices are needed to address problems with the random-access process.

On the other hand, due to their adaptable and highly transportable nature, airborne communication BSs are anticipated to play a significant role in the B5G/6G cellular infrastructure and therefore it is important to develop cost efficient solutions. UAV-assisted BSs can provide cost-effective cellular network coverage, as an agile wireless communication infrastructure, in some severe situations, such as during a crowded event when there is cell-level congestion, and the service provision is tampered with low performance.

In this framework, this 5G!Drones use-case suggests an effective installation of a single UAV-assisted wireless network in three dimensions (3D), improving the well-known air-to-ground (A2G) path model by assisting the ground base station using the UAV to serve random distributed consumers while considering the impact of the obstacle blockage. The goal of this use-case is to maximize the number of customers serviced by the UAV by optimizing the amount of available bandwidth that must be delivered.

These benefits of airborne BSs, along with the specifications set by the upcoming 5G (and later 6G) networks, have prompted research into a variety of drone-enabled and cellular-specific communication networks, including the study of air-to-ground channel characteristics, the best placement of drones (either as lone relays or as members of a swarm), and the optimization of flight trajectories.

2.2.4 Cellular UAV models controlled via mobile networks in the market

Starting in 2021, the world's largest drone manufacturer, DJI (estimated market share of commercial UAVs production is roughly 70% in 2021), offer a 4G dongle for the Mavic 3 model, through which the drone can be controlled, and video can be received over the 4G mobile network, in case the connection between the radio controller and the drone is lost. In 2022, a 4G dongle for the aforementioned DJI Mavic3 drone has been launched in many countries (China, Australia, USA, South Korea, and many European countries). The deployment of the DJI Mavic 3 with 4G dongle in each country depends on the radio communication regulation of the respective country. Each nation has its restrictions that regulate the use of radiofrequency equipment, which limits the usage of this relatively new technology in most countries[121].

[120] https://users.cecs.anu.edu.au/~Chris.Browne/student_work/example_work/15_2226_lp_jamesb.pdf

[121] https://www.droneblog.com/dji-mavic-3-4g-dongle/

Figure 50 DJI Mavic3 with 4G dongle

The DJI Mavic 3 4G dongle enables users to fly “without boundaries.” When the dongle is active, the remote controller signal becomes less important since the drone interacts with the device through a 4G network, allowing the pilot to fly beyond visual line of sight (BVLOS) with a range limited only by the battery’s power. The most significant drawback of this amazing system is that it is not available in all nations as the regulations differ around the globe. It is, however, DJI’s first official solution that allows one of their drones to fly without being limited by the range of the remote controller’s signal. This is something that might make professional pilots’ lives and operations easier and safer[122].

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One of the largest drone manufacturers, Parrot, will offer the Anafi drone with a 4G LTE module from 2022. Parrot ANAFI Ai is the first drone to use 4G as the main data link between the drone and the operator, which is a game changer for the drone industry. Users will no longer experience transmission limitations thanks to ANAFI Ai’s 4G connectivity, which enables precise control at any distance. For Beyond Visual Line of Sight flights, it stays connected even behind obstacles. It is worth noting that this drone uses the 700MHz frequency, which will be banned in the future for drones flying below 30m AGL[123].

[122] https://www.droneblog.com/dji-mavic-3-4g-dongle/

[123] https://www.parrot.com/en/drones/anafi-ai/technical-documentation/connectivity

From August 16, 2021, a drone with a 5G communication module will be offered by Qualcomm in cooperation with the ModalAI company[124]. The drone has a Quectel 5G modem on board, and the onboard computer uses a Kryo processor based on ARM architecture[125]. ModalAI also offers the Sentinel 5G drone from 2022, the cost of which is in the same order of magnitude as the Qualcomm-I 5G drone, as described in Figure 51 below.

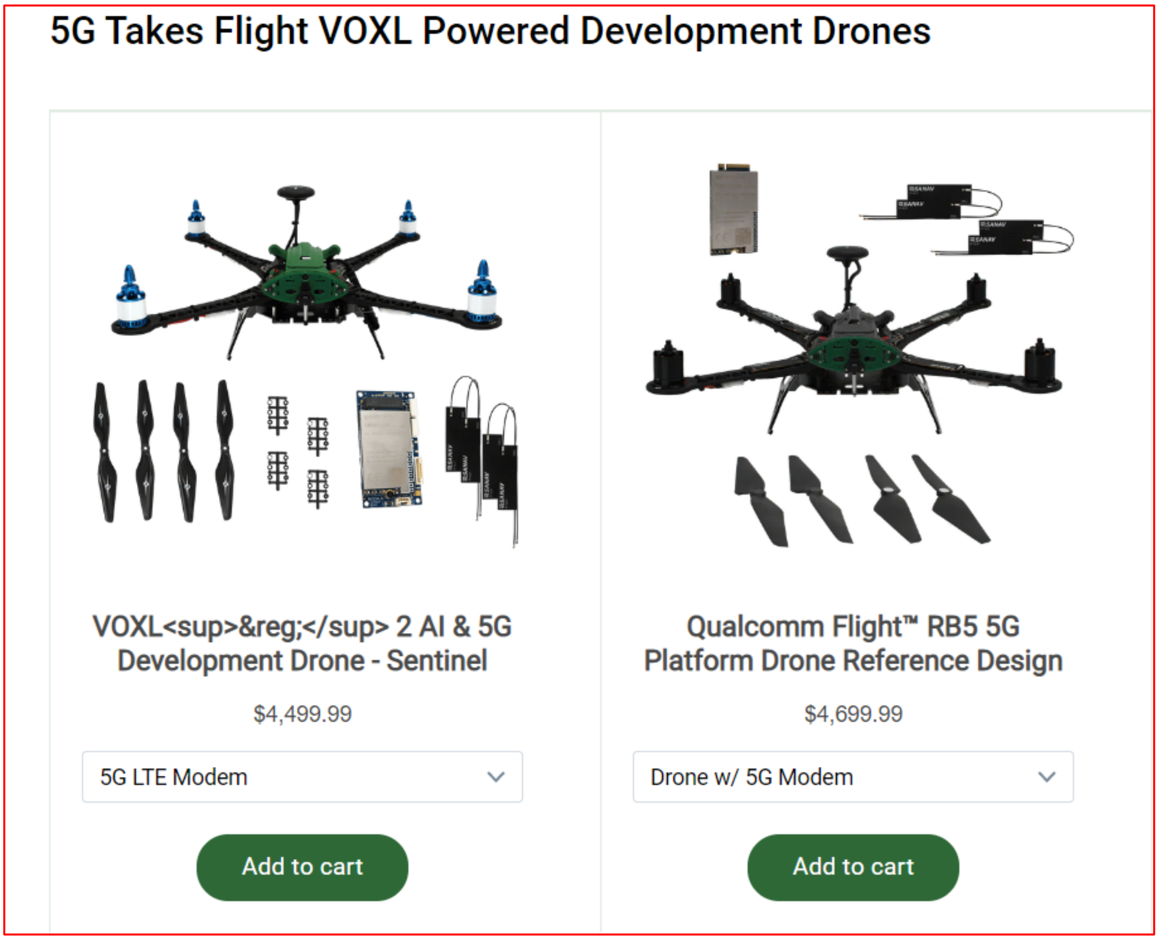

Figure 51 5G!Drones offered for sale by ModalAI.[126]

In summary, it should be noted that the drone manufacturers have understood that in order to use drones in urban conditions, it is necessary to control them via mobile communication, because the radio controllers do not reach the other side of the high-rise building. However, the deployment of cellular drones is limited in several aspects by regulation, which will be discussed in the next chapter.

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[124] https://www.qualcomm.com/products/application/industrial-commercial/robotics/flight-rb5-platform

[125] https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/qualcomm_flight-rb5-5g-platform-product-brief_87-28734-1.pdf

[126] https://www.modalai.com/pages/5-things-to-know-about-5g-drones

3 Regulatory Ecosystem in the 5G!Drones Context

As the 5G!Drones project executed UAV flights and trials during the period 2020-2022 in 3 EU countries, it is important to analyse the prevailing regulations and their regulatory impact in Europe. This regulatory analysis focuses on the points that affected the 5G!Drones project and as well as the latest EU regulatory framework (in effect since 2021).

3.1 Regulation Aspects

3.1.1 EU Regulatory Framework

The EU provides a regulatory framework for UAV operations and management, commonly called U-space regulation. Up to mid of 2022 the following regulations are in effect: EU 664/2021, EU 665/2021, EU 666/2021.The full U-Space regulation, including all updates, will be applicable as from 26 January 2023 (Figure 52).

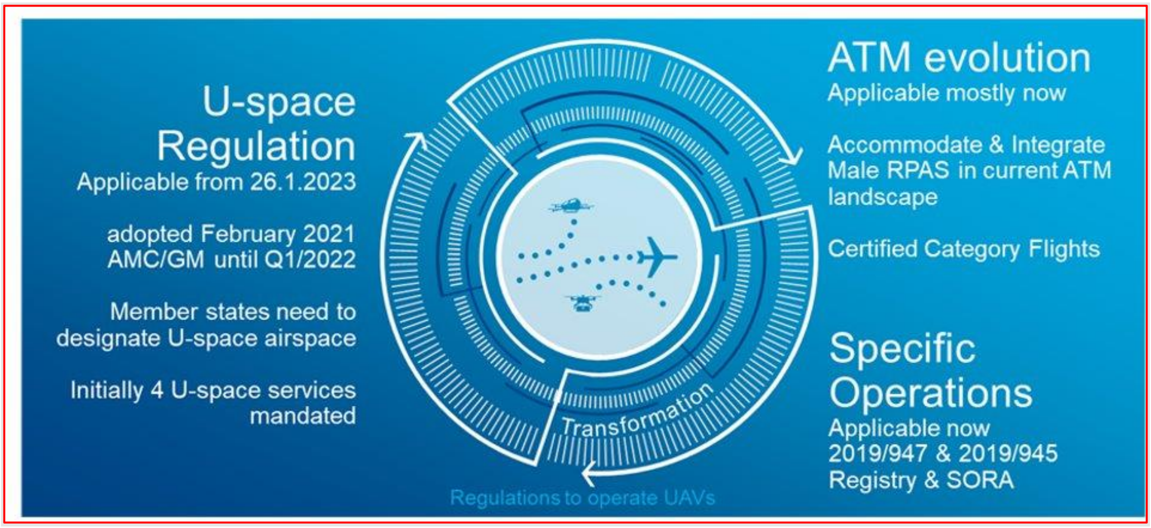

Figure 52: EU latest Regulatory framework updates[127]

- 2021/64 provides the regulatory framework for U-space, which regulates the technical and operational requirements for the U-space system – more details further down below.
- 2021/65 regulates requirements for providers of air traffic management/air navigation services and other air traffic management network functions in the U-space airspace designated in controlled airspace[128].
- 2021/66 is amending Regulation (EU) No 923/2012 as regards requirements for manned aviation operating in U-space airspace[129].

[127] https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX:32021R0664

[128] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R0665

[129] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0666

In the upcoming years, additional services will get regulated by, according to regulation releases as per U-space phases, already presented in Figure 47.

Regulation 2021/664 lists 4 mandatory U-space services, plus two optional ones (weather and conformance), refer to Figure 53: U-space Services[130]. In addition, the possibility of a ‘Common Information Service’ (CIS) is described.

Figure 53: U-space Services

1. **Network identification service**
A network identification service provides the identity and location of UAS during operations and shares relevant information with other U-space participants.

2. **Geo-awareness service**
A geo-awareness service provides the information about the airspace constraints, areas and defined UAS geographical zones information made available from stakeholders.

3. **Flight authorisation service**
A flight authorisation ensures that authorised operations do not conflict in time or space with other operations.

4. **Traffic information service**
A traffic information service informs U-space participants other air traffic that may be present nearby.

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[130] https://www.researchgate.net/publication/351174535_Unmanned_Aerial_Traffic_Management_System_Architecture_for_U-Space_In-Flight_Services

5. **Weather information service**
A weather information service provides additional information to U-space participants on meteorological parameters and forecasts

6. **Conformance monitoring service**
A conformance monitoring service provides alerting of non-conformance with the authorised flight authorisation and informs the U-space participants about deviations.

3.1.1.1 UTM

At the end of 2021 the European Union Aviation Safety Agency (EASA) published proposals for the Acceptable Means Compliance and Guidance Material (AMC & GM) for the U-space regulations in (EU) 2021/664, Regulation (EU) 2021/665 and Regulation (EU) 2021/666as NPA-2021-14[131].

The proposed AMC & GM shall provide the means to facilitate the implementation of the U-space services and to support the safe traffic management of unmanned aircraft that can be integrated with manned aviation in all types of environments.

Regarding UTM the following clarification is quite interesting:

Common information system (CIS)

"Member States may decide to designate a dedicated entity to provide the CIS on an exclusive basis in a given U-space airspace. Such 'single CIS provider' would make available the relevant information to all relevant operational stakeholders. The single CIS provider would need to be certified for the services it provides. The designation of a single CIS provider would need to be notified to other Member States as well as to the Agency. (d) In the absence of a single CIS provider, the common information is directly exchanged between the relevant operational stakeholders in a distributed, peer-to-peer communication architecture, whereby each data provider communicates with another USSP directly for sharing information. Each USSP needs to communicate with other data providers. A clear allocation of common information elements between Member States, ATS providers and USSPs would allow data users to find target data quickly and efficiently. In the absence of a single CIS provider, there is no need for an additional certification; the provision of common information elements by ATS providers and USSPs will be covered by their respective certificate and provisions of Regulation (EU) 2021/664 and amendment to Regulation (EU) 2017/373."[132]

This means that both a single CIS as well as multiple connected USSPs are a valid way forward for member states.

The AMC/GM provide detailed guidelines on the actual implementation of the U-space regulations, as an exemplary excerpt (Figure 54: Flight Authorization Flow) which describe the flow and states of a flight authorization process and its interaction with the conformance monitoring of related flights.

131 https://www.easa.europa.eu/downloads/134303/en

132 https://www.unmannedairspace.info/emerging-regulations/easa-publishes-u-space-acceptable-means-compliance-and-guidance-material-proposals/

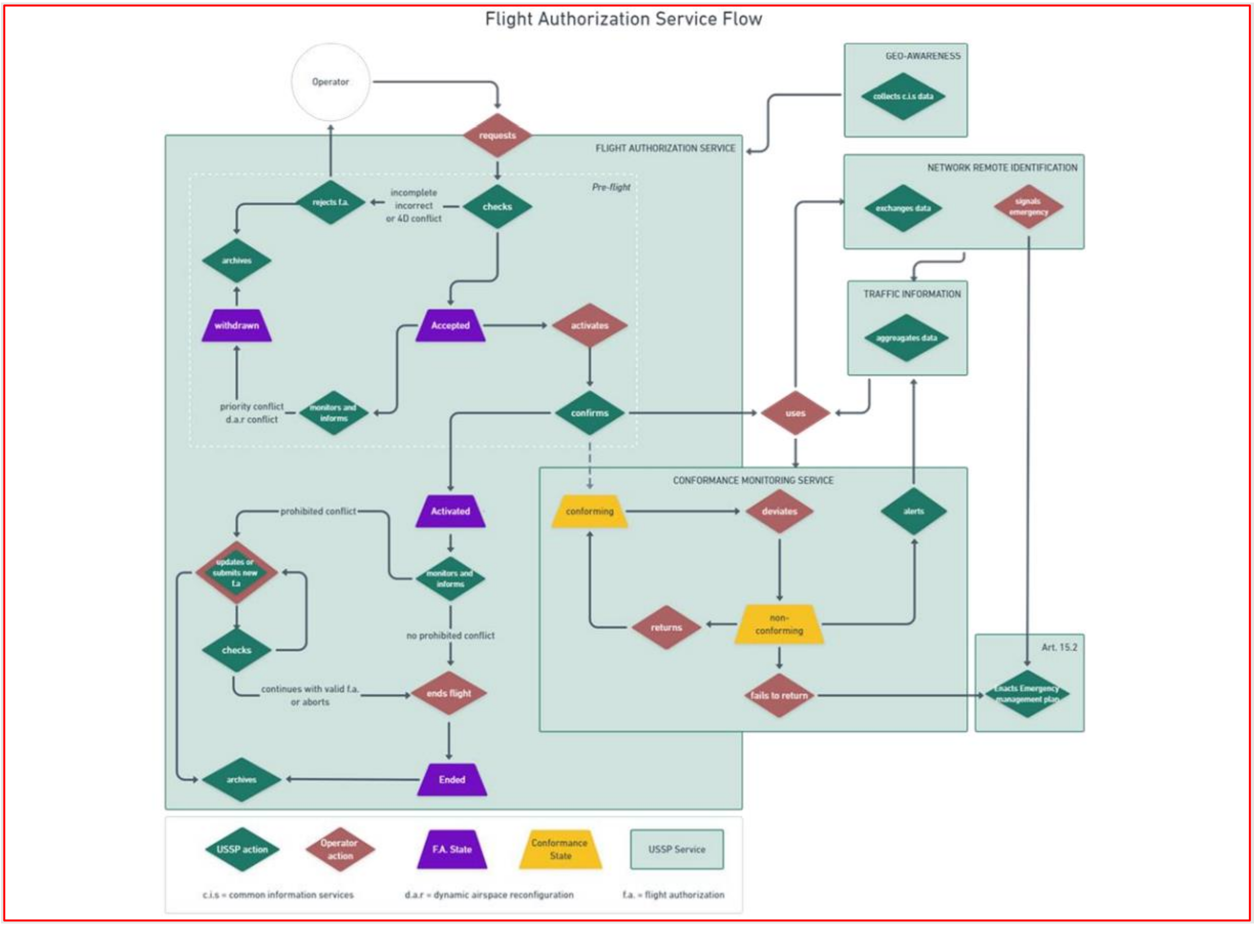

Figure 54: Flight Authorization Flow

The official release of AMC/GM is expected by the end of 2022.

3.1.1.2 EU Regulation 945/947

Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems and Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft has divided drone regulation into three categories, **Open, Specific and Certified categories** (Figure 55).

The open category's operations are low-risk operations, the Specific category operations are Medium-risk operations and the certified category's operations are High-risk operations. The open category is limited to Visual Line Of Site (VLOS) operations under 120-meter altitude and in sparsely populated areas where the Maximum take-off weight is less than 25kg. If the operation is Beyond Visual Line Of Site (BVLOS), altitude is more than 120 meters or the operation is in densely populated areas, the operation is in the specific category.

When operations involve large drones in controlled airspace, these operations are carried out in the certified category. EU Regulation 2019/947 and 2019/945 applicability dates were delayed from 1 July 2020 to 31 December 2020 due to the COVID-19 crisis. On 31 December 2020, the registration of drone operators and certified drones became mandatory and operations in the 'specific' category may be conducted after authorisation has been given by the National Aviation Authority. Between 31 December 2020 and 1 January 2023, drone users operating drones without class identification labels can continue to operate in the limited category under Article 22 of EU Regulation 2019/947. January 2023, all operations in the 'open' category and all drone operators must fully comply with EU Regulation 2019/947 and EU Regulation 2019/945[133].

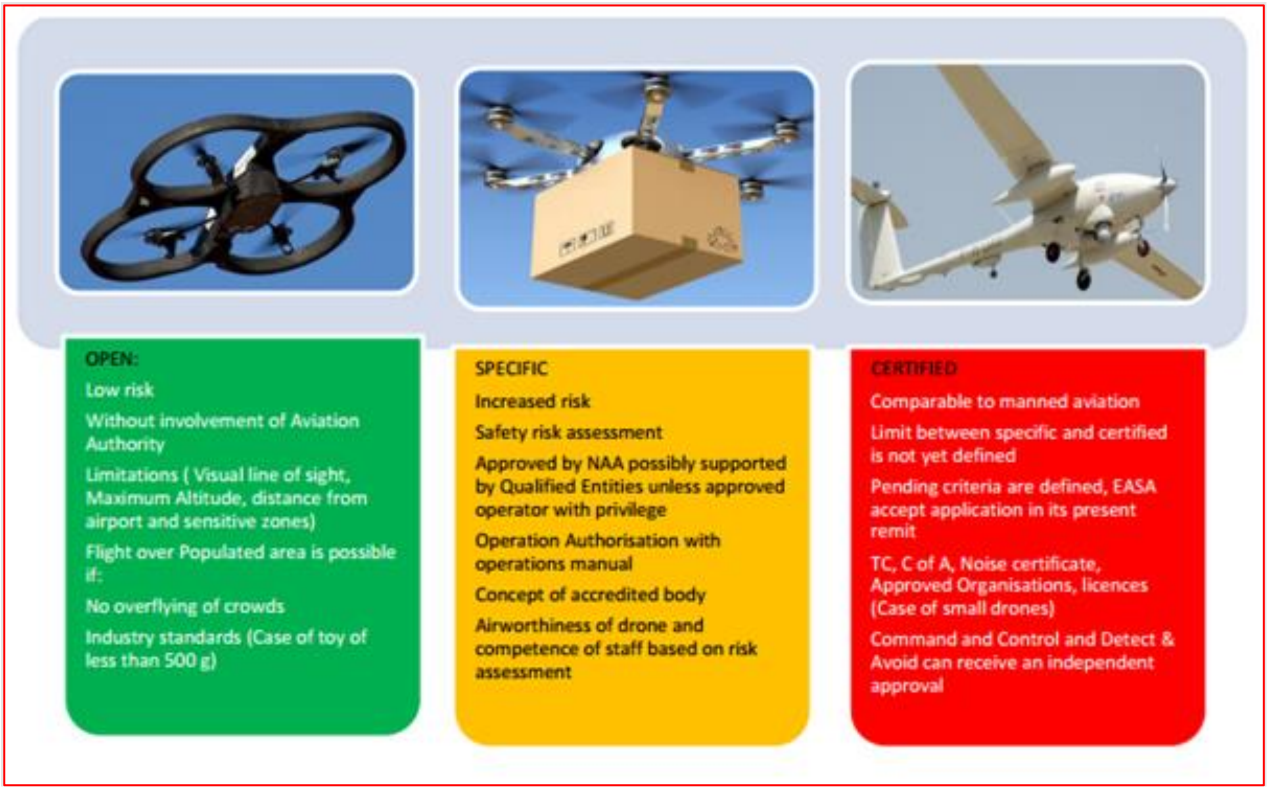

Figure 55: Three categories for unmanned aircrafts

3.1.1.2.1 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.

133 EU Regulation 2019/947 and EU Regulation 2019/945

Table 2 UAS classes and restrictions[134]

UAS		Operation		Drone Operator/pilot		
Class	MTOM	Subcategory	Operational restrictions	Drone Operator registration	Remote pilot competence	Remote pilot minimum age
Privately built	< 250 g	A1 (can also fly in subcategory A3)	- may fly over uninvolved people (should be avoided when possible) - no flying over assemblies of people	No, unless camera / sensor on board and a drone is not a toy	- no training needed	No minimum age
C0					- read user manual	16*, no minimum age if drone is a toy
C1	< 900 g		- No flying expected over uninvolved people (if it happens, should be minimised) - no flying over assemblies of people	Yes	- read user manual - complete online training - pass online theoretical exam	16*
C2	< 4 kg	A2 (can also fly in subcategory A3)	- no flying over uninvolved people - keep horizontal distance of 30 m from uninvolved people (this can be reduced to 5 m if low speed function is activated)	Yes	- read user manual - complete online training - pass online theoretical exam - conduct and declare a self-practical training - pass a written exam at the NAA (or at recognized entity)	16*
C3	< 25 kg	A3	- do not fly near people - fly outside of urban areas (150 m distance)	Yes	- read user manual - complete online training - pass online theoretical exam	16*
C4						
Privately built						

In the Open category, drones are divided into 6 classes. From 1 July 2022, all drones placed on the EU market must have class identification labels ranging from 0 to 6 from lighter to heavier models. The open category also divides operation into three subcategories A1, A2 and A3. Operations with privately built drones, or drones belonging to C0 are not needed for registration or exam to prove remote pilot competence if the drone doesn't have a camera/sensor on board and the drone is a toy. Drones with less than 900g belong to the C1 class and operations with these kinds of drones require passing the online theoretical exam and the drone operator registration. A drone with a Maximum Takeoff Weight (MTOW) of less than 4kg belongs to the A2 subcategory or A3 subcategory. If the operations are not near people and operations are done outside of urban areas, operations can be done in the A3 subcategory, which requires the online theoretical exam. When the operation is done near the people, but not over uninvolved people, the operation belongs to the A2 subcategory. A2 subcategory requires that the pilot has passed the A1/A3 online theoretical exam and passed a written exam at the NAA or recognised entity (Table 2).

3.1.1.2.2 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

[134] https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-unmanned-aircraft-systems-regulations-eu

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 standardised method – the SORA – that will be provided by EASA) and define mitigation measures, verify that they comply with a specific scenario defined by EASA (or the national aviation authority) or conduct operations based on Predefined Risk assessments (PDRA).

On that basis, they will be able to obtain authorization from the national aviation authority (in some cases a simple declaration may be enough). The authorization or the specific scenario will define the authorised operation and the applicable mitigation measures (drone technical requirements, pilot competence, etc.).

3.1.1.2.2.1 Standard Scenarios (STS)

Standard Scenario (STS) is a predefined operation, described in an appendix to EU regulation 2019/947. To date two STSs have been published, STS 1 and STS 2, and they require use of a drone with class identification label C5 or C6 respectively. If the operation falls under the STS and your drone bears this class identification label you are allowed to send a declaration to the NAA[135] where you are registered and just wait for the confirmation of completeness and receipt.

Based on the EU regulation 2020/639, Standard scenario 1 (‘STS-01’) covers operations executed in visual line of sight (‘VLOS’), at a maximum height of 120 m over a controlled ground area in a populated environment using a CE class C5 UAS. Standard scenario 2 (‘STS-02’) covers operations that could be conducted beyond visual line of sight (‘BVLOS’), with the unmanned aircraft at a distance of not more than 2 km from the remote pilot with the presence of airspace observers, at a maximum height of 120 m over a controlled ground area in a sparsely populated environment and using a CE class C6 UAS. Although EASA has defined two Standard scenarios, in practice drone operators haven’t been able to conduct operation within this regulation, because so far there are no C5 or C6 labelled drones in the market. However, we can expect C5 and C6 labelled drones to come to the market at the end of 2022 or the beginning of 2023.

3.1.1.2.2.2 Predefined Risk Assessment (PDRA)

For operations that require authorisation, it is possible to use the published predefined risk assessments (PDRA). In the case of a PDRA, the authority has already defined what are the conditions for the operation and based on the description the operator has to describe how it will fulfil these conditions. Table 3 below provides a summary of the PDRAs that have been published so far. The codification of a PDRA includes the letter ‘G’ or ‘S’ (e.g. PDRA-G01 or PDRA-S01): ‘G’ is used for generic PDRAs and ‘S’ is used for PDRAs that are derived from an STS whose level of prescriptiveness is the same as of the corresponding STS.

Therefore, those PDRAs, although they address UAS operations that are subject to operational authorisations (to allow the use of UAS without a class label), are expected to provide an even more simplified authorisation process compared to other (non-STS-related) PDRAs. Ideally, for UAS operations that are performed based on those PDRAs, the competent authorities may implement expedited operational-authorisation processes. Those processes may be based on the review of the documentation that is submitted by the UAS operator to support the declaration of compliance with the PDRA provisions (Table 3).

[135] https://www.easa.europa.eu/en/domains/civil-drones/naa

Table 3 List of PDRAs published as AMC to Article 11 of the UAS Regulation[136]

	PDRA-S01 “Mirror” of STS-01	**PDRA-S02** “Mirror” of STS-02	**PDRA-G01**	**PDRA-G02**
Visual Contact	Yes, VLOS	Yes, EVLOS is possible	Yes, EVLOS is possible	BVLOS
Area	under drone operator’s control	under drone operator’s control	sparsely populated	sparsely populated
Airspace	controlled or uncontrolled	controlled or uncontrolled	uncontrolled	reserved
Max. height	120m	120m	150m	
Drone properties	max. circumference of 3 m and/or 34 kJ	max. circumference of 3 m and/or 34 kJ	max. circumference of 3 m and/or 34 kJ	max. circumference of 3 m and/or 34 kJ
Class marking	not required	not required	not required	not required
Pilot skills	Online training and exam in accordance with ‘open’ A2. Additional practical experience at a recognised body.	Online training and exam in accordance with ‘open’ A2. Additional practical experience at a recognised body.	Case-specific, depending on the planned operation. Acquisition of knowledge relevant to the operation.	Case-specific, depending on the planned operation. Acquisition of knowledge relevant to the operation.

3.1.1.2.2.3 SORA

The operator must conduct a SORA risk assessment for the operation if the operation cannot be adapted to Open category rules or conditions of a predefined risk assessment or a Standard Scenario (STS).

SORA is divided into a 10 steps process; Concept of Operation (CONOPS) documentation, Determination of the intrinsic UAS ground risk class, Final Ground Risk Class (GRC determination, Determination of the initial air risk class (ARC), Residual Air Risk Class determination, Tactical Mitigation Performance Requirements (TMPR) and robustness levels, Final assignment of the specific assurance and integrity level (SAIL) and Operational Safety Objectives (OSO), Identification of the operational safety objectives (IOSO), Adjacent area and airspace considerations and Comprehensive safety portfolio. In a merged and summarised way, the most important to our analysis steps are presented below.

- **Concept of Operations (CONOPS)**

The first step of the SORA requires the applicant to collect and provide the relevant technical, operational and system information needed to assess the risk associated with the intended operation of the UAS.

The ConOps description is the foundation for all other activities, and it should be as accurate and detailed as possible. The ConOps should not only describe the operation, but also provide insight into the UAS operator’s operational safety culture. It should also include how and when to interact with the Air Navigation Service Provider (ANSP). Therefore, when defining the ConOps, the UAS operator should give due consideration to all the steps, mitigations and Operational Safety Objectives (OSO). Developing the ConOps can be an iterative process and therefore, as the SORA process is applied,

[136] https://www.bazl.admin.ch/bazl/en/home/drohnen/drohnen/wichtigsten-regeln/bewilligungen/pdra.html

additional mitigations and limitations may be identified, requiring additional associated technical details, procedures, and other information to be provided or updated in the ConOps.

- **Determination of the intrinsic UAS ground risk class (GRC) and Final GRC**

The intrinsic UAS ground risk relates to the risk of a person being struck by the UAS (e.g. in the case of a loss of UAS control). To establish the intrinsic GRC, the applicant needs the maximum UA characteristic dimension (e.g. the wingspan for a fixed-wing UAS, the blade diameter for rotorcraft, the maximum dimension for multi-copters, etc.) and the knowledge of the intended operational scenario. The applicant needs to have defined the area at risk when conducting the operation (also called the 'area of operation'). The operational scenarios describe an attempt to provide discrete categorisations of operations with increasing numbers of people at risk. SORA has defined 7 different operational scenarios including VLOS and BVLOS operations in controlled airspace, sparsely populated areas, populated areas and over an assembly of people. Operations that do not have a corresponding intrinsic GRC are not supported by the SORA methodology and cannot be conducted in the 'specific' category. Intrinsic GRC depends also on the maximum UAS characteristics dimensions (1m, 3m, 8m and >8m) and Typical kinetic energy expected (<700j, <34kj, <1084kj and >1094kj).

In case of a loss of control of the operation, the intrinsic risk of a person being struck by the UAS can be controlled and reduced by means of mitigation. The mitigations used to modify the intrinsic GRC have a direct effect on the safety objectives associated with a particular operation, and therefore it is important to ensure their robustness. The final GRC determination is based on the availability of these mitigations to the operation. The mitigations are divided into three types, which provide a list of potential mitigations and the associated relative correction factor. A positive number denotes an increase in the GRC, while a negative number results in a decrease in the GRC. All the mitigations should be applied in numeric sequence to perform the assessment.

- **Determination of the initial air risk class (ARC)**

The SORA uses the operational airspace defined in the ConOps as the baseline to evaluate the intrinsic risk of a mid-air collision, and by determining the air risk category (ARC). The ARC may be modified/lowered by applying strategic and tactical mitigation means. The application of strategic mitigations may lower the ARC level. An example of strategic mitigations to reduce the risk of a collision may be by operating during certain time periods or within certain boundaries. After applying the strategic mitigations, any residual risk of a mid-air collision is addressed by means of tactical mitigations.

Tactical mitigations take the form of detect and avoid (DAA) systems or alternate means, such as ADS-B, FLARM, U-space services or operational procedures. Depending on the residual risk of a mid-air collision, the tactical mitigation performance requirements (TMPR) may vary.

As part of the SORA process, the UAS operator should cooperate with the relevant service provider for the airspace (e.g. the ANSP or U-space service provider (USSP)) and obtain the necessary authorisations. Additionally, generic local authorisations or local procedures allowing access to a certain portion of controlled airspace may be used if available.

Irrespective of the results of the risk assessment, the UAS operator should pay particular attention to all the features that may increase the detectability of the UA in the airspace. Therefore, technical solutions that improve the electronic conspicuousness or detectability of the UAS are recommended.

The ARC is a generalised qualitative classification of the rate at which a UAS would encounter a manned aircraft in the specific airspace environment. However, it is recognised that the UAS operational volume may have a different collision risk from the one that the generalised initial ARC assigned. If an applicant considers that the generalised initial ARC assigned is too high for the condition in the local operational volume, then they should refer to Annex C of the EASA Easy Access Rules AMC[137] to

[137] https://www.easa.europa.eu/en/document-library/easy-access-rules

Article 11 for the ARC reduction process. If the applicant considers that the generalised initial ARC assignment is correct for the condition in the local operational volume, then that ARC becomes the residual ARC.

Although the static generalised risk put forward by the ARC is conservative, there may be situations where that conservative assessment may not suffice. It is important for both the competent authority and the UAS operator to take great care to understand the operational volume and under which circumstances the definitions in the ARC flowchart picture above could be invalidated. In some situations, the competent authority may raise the operational volume ARC to a greater level. The ANSP should be consulted to ensure that the assumptions related to the operational volume are accurate.

- ARC-a is generally defined as airspace where the risk of a collision between a UAS and a manned aircraft is acceptable without the addition of any tactical mitigation.
- ARC-b, ARC-c, ARC-d generally define volumes of airspace with increasing risk of a collision between a UAS and a manned aircraft.

During the UAS operation, the operational volume may span many different airspace environments. The applicant needs to perform an air risk assessment for the entire range of the operational volume

Tactical mitigations are applied to mitigate any residual risk of a mid-air collision that is needed to achieve the applicable airspace safety objective. Tactical mitigations will take the form of either ‘see and avoid’ (i.e. operations under VLOS), or they may require a system which provides an alternate means of achieving the applicable airspace safety objective (operation using a DAA, or multiple DAA systems). The EASA Easy Access Rules AMC to Article 11 (Annex D)[138] provides the method for applying tactical mitigations.

VLOS is considered to be an acceptable tactical mitigation for collision risk for all ARC levels. Notwithstanding the above, the UAS operator is advised to consider additional means to increase the situational awareness with regard to air traffic operating in the vicinity of the operational volume. In general, all VLOS requirements are applicable also to EVLOS. EVLOS may have additional requirements over and above those of VLOS. The EVLOS verification and communication latency between the remote pilot and the observers should be less than 15 seconds.

- **Final assignment of specific assurance and integrity level (SAIL) and Operational Safety Objectives (OSO)**

The SAIL parameter consolidates the ground and air risk analyses, and drives the required activities. The SAIL represents the level of confidence that the UAS operation will remain under control. After determining the final GRC and the residual ARC, it is then possible to derive the SAIL associated with the proposed ConOps.

The SAIL is not quantitative, but instead corresponds to:

- the OSO to be complied with
- the description of the activities that might support compliance with those OSO’s
- the evidence that indicates that the objectives have been satisfied.

The SAIL assigned to a particular ConOps is determined using the Table 4 below:

[138] https://www.easa.europa.eu/sites/default/files/dfu/Easy%20Access%20Rules%20for%20Unmanned%20Aircraft%20Systems%20%28Revision%20from%20September%202021%29.pdf#page=90

Table 4 SAIL determination

Residual ARC	a	b	c	d
Final GRC				
=<2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
>7	Certified category operation			

- **Identification of the Operational Safety Objectives (IOSO)**

The last step of the SORA process is to use the SAIL to evaluate the defences within the operation in the form of OSOs, and to determine the associated level of robustness.

Annex 6.1 provides further details on the OSO identification

3.1.1.2.2.4 Lights UAS operation Certificate (LUC)

A light UAS operator certificate (LUC) is an organisational approval certificate. Drone operators may ask the National Aviation Authority of registration to have their organisation assessed to demonstrate that they are capable of assessing the risk of an operation themselves. The requirements to be demonstrated by drone operators are defined in Part C of Regulation (EU) 2019/947. When the National Aviation Authority is satisfied, they will issue a light UAS operator certificate (LUC) and they will assign privileges to the drone operators based on their level of maturity. The privileges may allow the organisation to self-authorise operations without applying for an authorisation.

The privileges may be one or more of the following:

- Conduct operations covered by standard scenarios without submitting the declaration
- self-authorise operations conducted by the drone operator and covered by a PDRA without applying for an authorisation
- self-authorise all operations conducted by the drone operator without applying for an authorisation.

To obtain LUC status, organization must have LUC Manual, Internal Authorization, Safety Management System and Compliance Monitoring Program.

3.1.1.2.3 Certified category

The ‘certified’ category caters for the operations with the highest level of risk. Future drone flights with passengers on board such as the air taxi, for example, will fall into this category. The approach used to ensure the safety of these flights will be very similar to the one used for manned aviation. For this reason, these aircraft will always need to be certified (i.e. have a type certificate and a certificate of airworthiness), the UAS operator will need an air operator approval issued by the competent authority and the remote pilot is required to hold a pilot license.

In the long term, EASA expects that the level of automation of drones will gradually increase up to having fully autonomous drones without the need of the intervention of a remote pilot. In order to allow operations in the certified category almost all the aviation regulations will need to be amended. So this will be a major task, and therefore we may expect that certified class regulation will take several years to implement.

EASA decided to conduct this activity in multiple phases and to address first the following three types of operation:

- **Operations type #1:** International flight of certified cargo drones conducted in instrumental flight rule (IFR) in airspace classes A-C and taking-off and landing at aerodromes under EASA's scope. For example, an unmanned A320 transporting a cargo from Paris to New York.
- **Operations type #2:** Drone operations in urban or rural environments using predefined routes in airspaces where U-space services are provided. This includes operations of unmanned drones carrying passengers or cargo. For instance, air-taxi or package delivery services that come directly to your balcony or the roof of your building or your front yard.
- **Operations type #3:** Operations as in type #2, but conducted with an aircraft with a pilot on board. Actually, this is expected to cover the first type of air taxi operations, where the pilot will be on board. In a second phase the aircraft will become remotely piloted (operations type 2)

3.1.2 Overview of US Regulation Framework related to UAVs and 5G!Drones

In the USA, the FAA (Federal Aviation Administration) is responsible for issuing, enforcing, and supervising UAVs. Separate requirements have been established for public safety drone operators, certified remote pilots, model aircraft flyers, drone racers, or Advanced Air Mobility (AAM) operators.

There are a total of 869,731 drones registered in the US. Of these, 330,575 are Commercial Drones and 535,524 are recreational drones and 3,632 are heavier drones (weighing over 25kg). There are 302,499 certified remote pilots[139]. There is a separate process for registering drones weighing more than 25 kg[140].

FAA rules apply to the entire USA airspace there is no "unregulated" airspace. Drone operators should be familiar with the difference between controlled and uncontrolled airspace, and where they can legally fly. Controlled airspace is found around some airports and at certain altitudes where air traffic controllers are actively communicating with, directing, and separating all air traffic. Other airspace is considered uncontrolled in the sense that air traffic controllers are not directing air traffic within its limits. In general, you can only fly your drone in uncontrolled airspace below 400 feet above the ground (AGL). Commercial drone operators are required to get permission from the FAA before flying in controlled airspace.

Drone pilots planning to fly under 400 feet in controlled airspace around airports must receive an airspace authorization from the FAA before they fly. Recreational users who only fly their drone for fun, have an improved app – B4UFLY – to help show where they can and cannot fly with interactive maps. The FAA has partnered with Aloft (formerly Kittyhawk) to redevelop the FAA's first mobile application, to improve the user experience so that recreational flyers know whether it is safe to fly their drone. The app provides situational awareness to recreational flyers and other drone users. It does not allow users

139 https://www.faa.gov/uas

140 https://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/ua

to obtain airspace authorizations to fly in controlled airspace, which are only available through the FAA's Low Altitude Authorization and Notification Capability (LAANC)[141].

LAANC is available to pilots operating:

- under the Small UAS Rule Part 107 or
- under the exception for Recreational Flyers.

There are two ways to use LAANC:

- Submit a near real-time authorization request for operations under 400 feet in controlled airspace around airports (available to Part 107 Pilots and Recreational Flyers).
- Submit a "further coordination request" if you need to fly above the designated altitude ceiling in a UAS Facility Map, up to 400 feet.

LAANC is available at 726 airports. To fly in controlled airspace near airports not offering LAANC, operator can use the manual process to apply for an authorization. Remote pilots can get access through one of the FAA Approved LAANC UAS Service Suppliers. Companies Providing Public LAANC Services in the USA[142]:

- Airbus
- Airspacelink
- Aloft
- Avision
- eTT Aviation
- UASidekick
- Wing

To fly in controlled airspace that requires a waiver AND an airspace authorization. Remote Pilot must apply for both through the FAA's DroneZone. UAS Facility Maps show the maximum altitudes around airports where the FAA may authorize part 107 UAS operations without additional safety analysis. The maps should be used to inform requests for part 107 airspace authorizations and waivers in controlled airspace. Figure 56 below describes maximum altitudes (in feet) around the Nashville International Airport. This shows that it is not allowed to fly near the airport (max ceiling 0 feet) and a little further away it is already possible to use the airspace up to a height of 100 feet (30m).

[141] https://www.faa.gov/uas/getting_started/b4ufly

[142] https://www.faa.gov/uas/getting_started/laanc

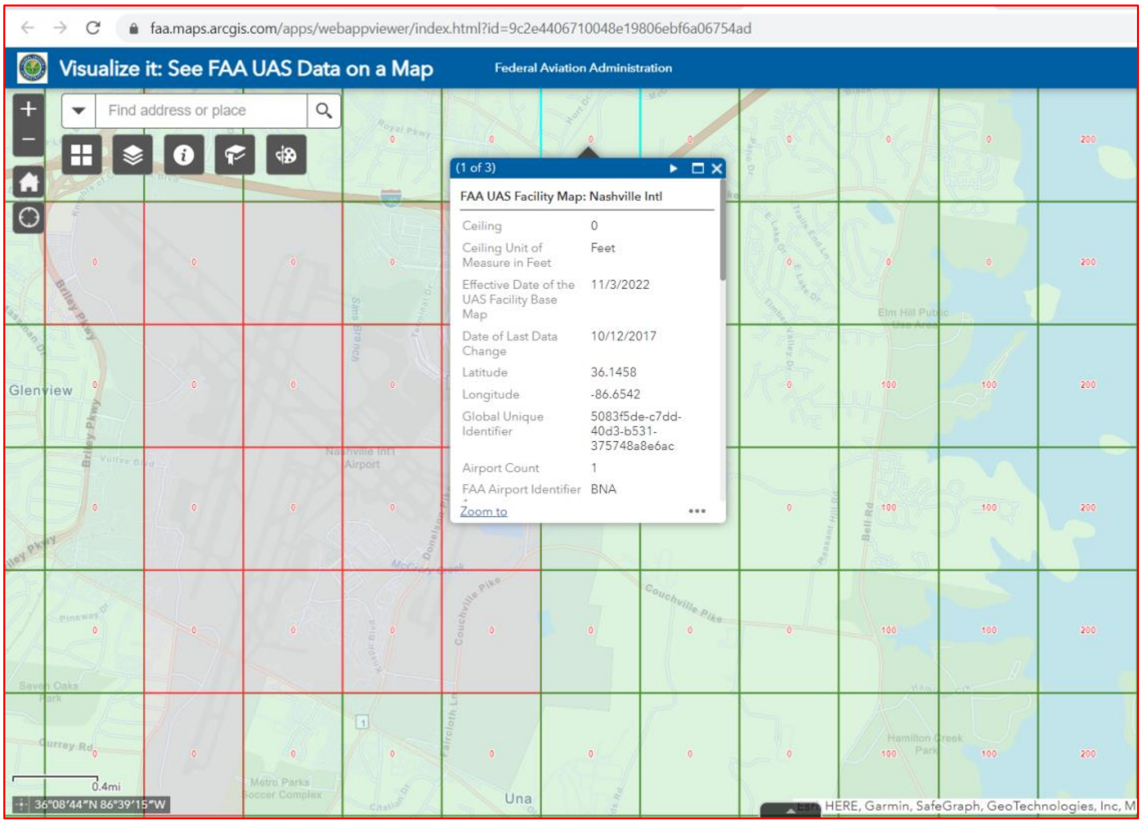

Figure 56: UAS Facility map around the Nashville International Airport

UAS Facility Maps (Figure 56) show the maximum altitudes around airports where the FAA may authorize part 107 UAS operations without additional safety analysis[143].

These maps do not authorize operations in these areas at the depicted altitudes – they are for informational purposes only. Operators must still apply to operate in controlled airspace (Class B, C, D, or surface area E) by completing a Part 107 Airspace Authorization request in LAANC or the FAA Drone Zone, or a Waiver Application in the FAA DroneZone. The maps should be used to inform requests for part 107 airspace authorizations and waivers in controlled airspace.

In general, one can only fly his drone in uncontrolled airspace below 400 feet above the ground (AGL). Commercial drone operators are required to get permission from the FAA before flying in controlled airspace[144].

[143] https://www.faa.gov/uas/commercial_operators/uas_facility_maps

[144] https://www.faa.gov/uas/getting_started/where_can_i_fly/airspace_101#:~:text=Other%20airspace%20is%20considered%20uncontrolled,above%20the%20ground%20(%20AGL%20)

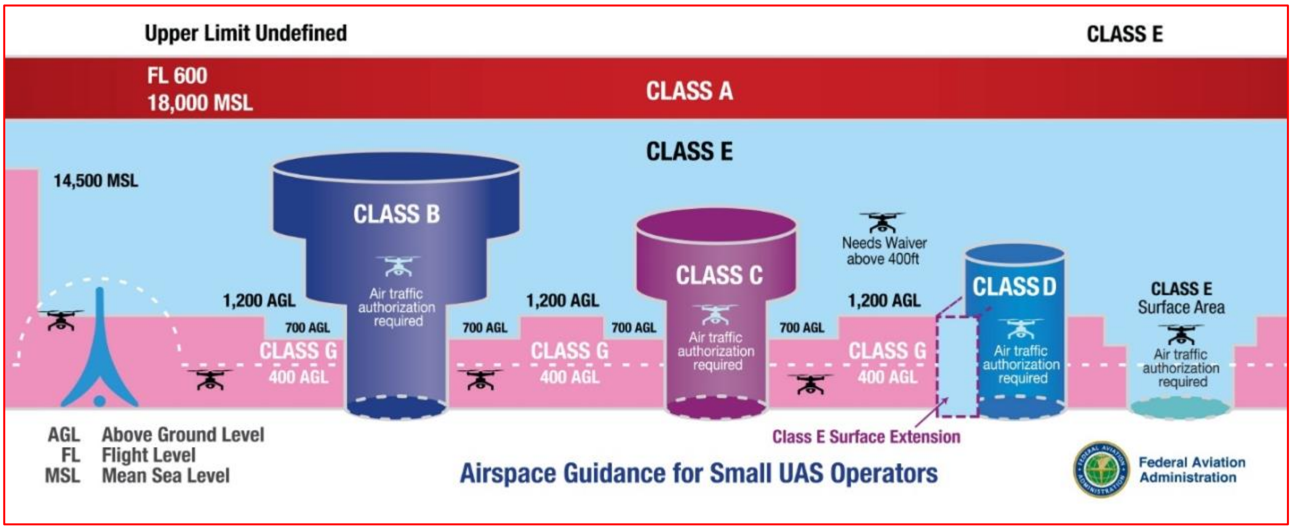

Figure 57: Illustration of Airspace Guidance for Small UAS Operators

Drones are prohibited from flying over designated national security sensitive facilities. Operations are prohibited from the ground up to 400 feet above ground level and apply to all types and purposes of UAS flight operations[145] (Figure 57).

3.1.2.1 Regulation of drone delivery flights Part 135 certification

From 2017 through 2020 the Unmanned Aircraft Systems (UAS) Integration Pilot Program (IPP) focused on testing and evaluating the integration of civil and public drone operations into our national airspace system. This work continues under the UAS BEYOND program which focuses on the remaining challenges of UAS integration, including beyond visual line of sight (BVLOS) operations, societal and economic benefits of UAS operations, and community engagement. Participants in these programs are among the first to prove their concepts, including package delivery by drone through part 135 air carrier certification. Part 135 certification is the only path for small drones to carry the property of another for compensation beyond visual line of sight.

All part 135 applicants must go through the full five phases of the certification process. The FAA issues air carrier certificates to U.S. applicants based on the type of services they plan to provide and where they want to conduct their operations. Operators must obtain airspace authorizations and air carrier or operating certificates before they can begin operations.

The FAA issued the first Part 135 Single pilot air carrier certificate for drone operations to Wing Aviation, LLC in April 2019. The FAA later issued Wing a Standard Part 135 air carrier certificate to operate a drone aircraft in October 2019. Wing Aviation is part of the Integration Pilot Program (IPP), delivering food and over-the-counter pharmaceuticals directly to homes in Christiansburg, VA. UPS Flight Forward, Inc., another participant in the IPP, was the first company to receive a Standard Part 135 air carrier certificate to operate a drone aircraft. On September 27, 2019, UPS Flight Forward conducted its first package delivery by drone with its part 135 certification when it flew medical supplies at WakeMed hospital campus in Raleigh, NC.

Amazon, a PSP participant, is the first company to operate a drone larger than 55lbs under a standard Part 135 air carrier certificate. Amazon began commercial operations in August 2020. They currently

145 https://www.faa.gov/uas/critical_infrastructure

deliver Amazon products in Oregon and Northern California, with further expansion planned for this year. On June 17, 2022, Zipline became the fourth drone operator to receive a part 135 certificate to be authorised to operate as an air carrier and conduct common carriage operations. This is the first part 135 certificate issued to an operator under the BEYOND program and the first fixed wing part 135 UAS operator to be certified[146].

The Operation of Unmanned Aircraft Systems Over People final rule (effective from April 21, 2021) is the next incremental step towards further integration of unmanned aircraft (UA) in the National Airspace System. The final rule allows routine operations over people and routine operations at night under certain circumstances[147].

3.1.2.2 Remote ID for drones

Remote ID is the ability of a drone in flight to provide identification and location information that can be received by other parties. Remote ID helps the FAA, law enforcement, and other federal agencies find the control station when a drone appears to be flying in an unsafe manner or where it is not allowed to fly. Remote ID also lays the foundation of the safety and security groundwork needed for more complex drone operations.

The final rule on remote ID will require most drones operating in US airspace to have remote ID capability. Remote ID will provide information about drones in flight, such as the identity, location, and altitude of the drone and its control station or take-off location. Authorised individuals from public safety organizations may request identity of the drone's owner from the FAA[148].

All drone pilots required to register their UAS must operate their aircraft in accordance with the final rule on remote ID beginning September 16, 2023, which gives drone owners sufficient time to upgrade their aircraft. Whether using a Standard Remote ID Drone or a remote ID broadcast module, the message elements must be broadcast from take-off to shutdown. A Standard Remote ID Drone or a drone with a remote ID broadcast module must transmit the following message elements:

- A unique identifier for the drone
- The drone's latitude, longitude, geometric altitude, and velocity
- An indication of the latitude, longitude, and geometric altitude of control station (standard) or take-off location (broadcast module)
- A time mark. and
- Emergency status (Standard Remote ID Drone only)

Almost all of the final rule on remote ID becomes effective April 21, 2021. Drone manufacturers must comply with the final rule's requirements for them. There are three ways drone pilots will be able to meet the identification requirements of the remote ID rule:

- Operate a Standard Remote ID Drone that broadcasts identification and location information about the drone and its control station. A Standard Remote ID Drone is one that is produced with built-in remote ID broadcast capability in accordance with the remote ID rule's requirements.

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146 https://www.faa.gov/uas/advanced_operations/package_delivery_drone

147 https://www.faa.gov/uas/commercial_operators/operations_over_people

148 https://www.faa.gov/uas/getting_started/remote_id

- Operate a drone with a remote ID broadcast module. A broadcast module is a device that broadcasts identification and location information about the drone and its take-off location in accordance with the remote ID rule's requirements. The broadcast module can be added to a drone to retrofit it with remote ID capability. Persons operating a drone with a remote ID broadcast module must be able to see their drone at all times during flight.
- Operate (without remote ID equipment) at FAA-recognised identification areas (FRIAs) sponsored by community-based organizations or educational institutions. FRIAs are the only locations unmanned aircraft (drones and radio-controlled airplanes) may operate without broadcasting remote ID message elements.

Figure 58 below describes the Remote ID system in the USA and how the Remote ID Rule can be met..

Figure 58: 3 Ways drone pilots can meet Remote ID Rule [149]

3.1.3 Radio Communication Regulation in Europe for the use of 5G communication to control UAVs

On 17.11.2022, the ECC (Electronic Communication Committee) adopted ECC Decision (22)07 "Harmonised technical conditions of the usage of aerial UE for communications based on LTE and 5G NR in the bands 703-733 MHz, 832-862 MHz, 880-915 MHz, 1710-1785 MHz, 1920-1980 MHz, 2500-2570 MHz and 2570-2620 MHz harmonised for MFCN" (also referred as Decision 22-07[150]).

The decision states that in CEPT (Conférence Européenne des administrations des Postes et des Télécommunications (European Conference of Postal and Telecommunication Administrations) countries, there is a fast-growing demand to operate aerial UE (User equipment) in particular under beyond-visual-line-of-sight (BVLOS) conditions, mainly for professional purposes. To enable these kinds of applications, there is the need for communication links between the aerial UE and mobile/fixed communication networks (MFCN) using bands harmonised for MFCN.

In this Decision, the term aerial UE refers to a UE supporting UAS features and services and requiring an aerial subscription. An aerial UE is installed either on-board an Unmanned Aircraft (e.g. drones) or on-board manned aircraft (e.g. helicopter). It identifies itself to the mobile network as being in this class.

Based on CEPT analysis: ECC Report 309[151] and ECC Report 348[152], this ECC Decision provides harmonised technical conditions for the usage of aerial UE for communications in the following MFCN

149 https://www.faa.gov/uas/getting_started/remote_id
150 https://docdb.cept.org/document/28575

151 "Analysis of the usage of aerial UE for communication in current MFCN harmonised bands", approved July 2020 https://docdb.cept.org/document/15236
152 ECC Report 348: "Usage of aerial UE in 1.8 GHz, 2 GHz and 2.6 GHz frequency bands with MFCN AAS base stations"

harmonised bands: 703-733 MHz, 832-862 MHz, 880-915 MHz, 1710-1785 MHz, 1920-1980 MHz, 2500-2570 MHz and 2570-2620 MHz.

After the approval of ECC Report 309, ECC recognised a demand for further studies of aerial UE connected to 5G NR AAS base stations on the ground in the 1.8 GHz, 2 GHz and 2.6 GHz frequency bands and developed ECC Report 348 accordingly. According to ECC Report 309 and ECC Report 348, the communication links of aerial UE are intended to be used primarily for data communication within MFCN bands.

This ECC Decision has been developed based on assumptions, analysis and main conclusions of ECC Report 309 and ECC Report 348. These Reports assume that aerial UE uses data payload. For aerial UE that do not use data payload (i.e. command and control aerial UE only) less stringent regulatory provisions might be applicable but further studies are required before these provisions can be relaxed. ECC Report 348 also includes a technology comparison between LTE and 5G NR. Based on this analysis, technical and operational conditions such as OOBE limits or no-transmit zone based on the studies from the ECC Report 309 are valid for both LTE and 5G NR aerial UE.

This harmonised framework is limited to these two MFCN technologies which are already deployed and available in different MFCN frequency bands. Studies have been performed based on standardised LTE and 5G NR UE with usage of aerial UE operating up to 10000 m altitude with the assumption of usage of already existing MFCN base stations (BS), which are typically deployed to provide effective coverage at ground level. At this stage, ECC noted that mobile operators do not intend to develop specific network planning to respond to these new aerial use cases.

ECC decided that:

- Depending on the market demand, CEPT administrations shall allow the usage of aerial UE in the 880-915 MHz and 1920-1980 MHz frequency band without specific operational and technical conditions beyond those already applicable to UE in ECC Decisions in the given bands.

- For operation of aerial UEs in the bands 703-733 MHz, 832-862 MHz, 1710-1785 MHz, 2500-2570 MHz and 2570-2620 MHz, CEPT administrations shall implement the operational and technical conditions.

It is also stipulated that the operational conditions to be defined and implemented at national level provide additional measures to the technical conditions in order to protect other services.

In specific, 703-733 MHz: Protection of DTT receivers and RAS sites:

- Aerial UE operating in 703-733 MHz should not transmit when less than 30 m above ground level to avoid interference to DTT receivers. Another frequency band than 703-733 MHz shall be used for landing and take-off.

- Nationally determined no-transmit zones are required around radio astronomy stations sites operating in 1400-1427 MHz for aerial UE operating in the 703-718 MHz frequency band, as appropriate.

- ECC Decision (22)07 “Harmonised technical conditions of the usage of aerial UE for communications based on LTE and 5G NR in the bands 703-733 MHz, 832-862 MHz, 880-915 MHz, 1710-1785 MHz, 1920-1980 MHz, 2500-2570 MHz and 2570-2620 MHz harmonised for MFCN”

Based on ECC Decision No. 22(07)[153], member states will introduce national regulations starting in 2023, which will be notified to ECC. The 700MHz frequency is extremely important when using 5G communication for UAV control purposes, because this frequency has a larger coverage area and can therefore be relied on when planning UAV C2 systems and operations. Considering the upcoming regulation that the 700MHz frequency must be used during drone take-off and landing (i.e. up to a height of 30m AGL), it is necessary to develop additional technologies that turn off the said frequency when the UAV is lower than 30m AGL. However, this limits the use of the 5G network for controlling drones outside of cities, where the 700MHz frequency is planned to cover larger areas than the 3.5GHz frequency.

3.2 5G!Drones Platform Specific National Regulations and Procedures

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

3.2.1 France

3.2.1.1 French UAV Regulation

As any other European country, France is now in the transition period between the French UAV regulation and the European UAV regulation until the end of 2025. The European rules for the open and specific categories are applicable.

The following sections describe the additional elements the French regulation requests and allows, in addition to the European regulation described in the section above.

- **French standard scenarios**

In the specific category, drones can fly following standard scenarios, and using their PDRA for risk assessment. In France, and until the end of 2025, the French standard scenarios S1, S2 and S3 remain usable with certified drones in these scenarios. Only the S4 scenario was removed. It was once approved to fly in BVLOS with no distance limitation from the pilot.

These French standard (Table 5) scenarios are 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 the pilot and its own requirements for the pilot and company operating the drone.

Table 5 French Standard Scenarios

Scenario	**UAV MTOW** **≤ 2 kg**	**UAV MTOW** **2 kg < M ≤ 8 kg**	**UAV MTOW** **8 kg < M ≤ 25 kg**
Scenario S1:	Distance to pilot < 200 m Required: UAV pilot license Design Certificate (required): No Max height: 120 m		

[153] https://docdb.cept.org/document/28575

VLOS and unpopulated area			
Scenario S2: **BVLOS and unpopulated area**	Distance to pilot < 1000 m Required: UAV pilot license Design Certificate (required): Yes		
Max height (m)	120	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 license Max height: 120 m **Specific 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 authorisation from DGAC

Drone registration and French digital identification

The French regulation requests each drone over 800 g must be registered to the DGAC through AlphaTango website 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. The drone above 800 g must also have its French digital identification using a specific WiFi beacon.

- **Use of sensors and cameras**

If the drone uses cameras or sensors outside the visible spectrum, a request has to be sent to the prefecture. If the purpose of the flight is photo shooting, a declaration has to be sent to the DSAR.

- **Declaration prior flights**

Flights within an urban area need to be declared at least 5 days before the flight to the local prefecture. BVLOS flights need a declaration to the army ministry at least 30 days before the flight.

3.2.1.2 French Spectrum Regulation and Procedures

Drones are usually using the open spectrum which does not require authorisation from the authorities. The usual frequency bands used in drones in this open spectrum are as below (Table 6).

Table 6 Frequency bands commonly used on UAVs in France

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

Regarding the other frequencies, and especially the 5G bands, a specific authorisation needs to be granted by the French radio frequency authority, the ARCEP to be able to use it.

3.2.2 Finland

3.2.2.1 Finnish UAV Regulation

Finland has been having the most liberal UAS regulation in the world before the harmonised EU regulation. It was possible to have authorisation for BVLOS flights by reserving Temporal Danger airspace before the new EU regulation was effective. Finland has adopted the new regulations and therefore operators can apply specific category operational authorisation based either on the predefined risk assessment (PDRA) published by EASA or based on the operations risk assessment (SORA). Finland doesn't have national Standard Scenarios. Operation in the 'specific' category can comply with the standard scenarios published by EASA after 2 December 2023 when drones are marked with class identification labels C5 and C6.

For Finnish drone users, the regulation introduces an obligation to register as a drone operator in the new national register. In the past, the obligation to notify on the use of remotely piloted aircraft has only applied to the professional users of drones. Registration is required according to the new rules if the pilot is flying a drone weighing 250 g or more or a drone with a camera. When the pilot is flying a drone weighing less than 250 g and has no camera or a drone that is defined as a toy, there is no requirement to register as a drone operator.

An operator in the 'specific' category may apply for a Light UAS Operator Certificate (LUC operator certificate). However, this requires experience in operating in the 'specific' category, a mature organisational management system and completing several operational authorisation processes.

- **Managing airspace for UAS operations**

For drone operations, airspace usage is managed in Finland using Temporal Danger-, Temporal Restriction, or UAS geographical zones. Finnish CAA, Traficom may establish temporary danger areas or restrict aviation in a specific area for a certain period. Operators can apply for a temporary danger area for example, if the operator wants to fly an unmanned aircraft beyond visual line of sight. For each temporary airspace reservation, it is required to publish AIP Supplement at least 2 weeks before the start of the activity. Traficom will consult various aviation stakeholders before making a decision to establish temporary airspace reservations. Temporary airspace reservation applications shall be submitted to Traficom no later than 8 weeks before the planned start of the operation. A fee is charged for establishing a temporary airspace reservation as established in the Decree on Traficom's service fees by the Ministry of Transport and Communications.

Traficom can also establish UAS geographical zones to protect a specific area or to allow a certain type of unmanned aircraft systems to operate. UAS geographical zone applies only to unmanned aerial vehicles and may be of a prohibitive, restrictive, or permissive nature. The UAS geographical zone established by Traficom's decision can be valid for a maximum of 12 months. More permanent zones may be included in regulation OPS M1-29, which will be reviewed annually, for a period not exceeding three years at a time. All established zones are published on Traficom's drone info website[154], where the zones can also be downloaded in machine-readable form.

Traficom may establish a UAS geographical zone in which the operation of unmanned aircraft is prohibited or restricted for an indispensable cause. The decision or regulation may stipulate that following certain conditions, the UAS operations are nevertheless permitted in such a zone. However, flights conducted specifically on behalf of the entity responsible for the protected zone are allowed. Traficom may designate certain geographical zones in which UAS operations are exempt from one or more of the 'open' category requirements. Such UAS geographical zones may be established for commercial, hobby or research and experimental reasons based on an application and reasoning by a UAS operator. Traficom's decision or regulation may impose various conditions and restrictions on unmanned aircraft systems and their operators regarding operations in such a zone

3.2.2.2 Finnish Spectrum Regulation and Procedures

Traficom steers and supervises the use of the radio spectrum in Finland. By planning the use of spectrum, Traficom aims to ensure that sufficient radio frequencies, that are as interference-free as possible, are available to radio systems.

Traficom steers the use of radio spectrum for UAS in two categories, Radio frequencies for Command-and-Control Links (C2Links) and Payload frequencies.

- **Command and Control Links**

Command and Control Links enable the remote pilot, who is on the ground, to control the aircraft using command and control links and receive real-time information about the aircraft systems, such as the rotational speed of motors.

The most commonly used frequencies for controlling drones (from ground to air) are the ones for license-exempt radio equipment:

- 2400.000–2483.500 MHz, in which case the transmitter's effective radiated power is either
  - ≤100 mW EIRP, if the applicable standard is EN 300 328 on the digital wideband data transmission equipment (WAS), or
  - ≤10 mW EIRP, if the applicable standard is EN 300 440 on general short-range devices (SRD).
- 5470.000–5600.000 MHz and 5650.000–5725.000 MHz, in which case the transmitter's effective radiated power is ≤ 1 W EIRP and the power spectral density of transmission is ≤ 50 mW/1 MHz EIRP. The applicable standard is EN 301 893 on RLAN equipment. (The use of this frequency band is being discussed within international cooperation. The results may lead to removing this frequency band from being used on board aircraft. With equipment taken into use after 17 December 2021 it is not allowed to use frequency band 5600.000–5650.000 MHz on board airborne aircraft or in other equipment used for aviation.)
- 5725.000–5875.000 MHz, in which case the transmitter's effective radiated power is ≤25 mW EIRP and the applicable standard is EN 300 440 on general SRD.

[154] droneinfo.fi

Other frequency bands suitable for controlling drones and remotely piloted aircraft can be found in the Traficom's Regulation 15.

The frequency band 5030–5091 MHz is, according to the Radio Regulations published by the International Telecommunication Union ITU, allocated to the aeronautical mobile (route) service and limited to aeronautical systems standardised internationally by the International Civil Aviation Organization ICAO.

- **Payload frequencies**

Payload refers to other radio equipment than those used for command and control links. The most common payload device is a camera that can send real-time video feed from the aircraft to the ground. A thermographic camera or different measuring equipment may also be included in the payload.

Frequency bands 2400.000–2483.500 MHz, 5470.000–5600.000 MHz, 5650.000–5725.000 MHz (see usage restriction above) and 5725.000–5875.000 MHz may be used for the payload devices of an aircraft in addition to command and control links.

The frequency 1320 MHz is only meant for sending video feed from aircraft to the ground. Using this frequency requires a radio license that can only be obtained for a fixed period.

- **Use of mobile network frequencies**

Under Traficom's Regulation 15, mobile network terminal devices may be used on board airborne aircraft without a license if they are needed for certain official duties of the authorities or functions vital for the security of supply. This is a fixed-term arrangement valid until 31 March 2024.

If activities do not concern the authorities' official duties or functions vital for the security of supply, as referred to in Regulation 15, Traficom may also, with the consent of the relevant mobile operator, grant a radio license that enables using mobile network terminal devices on board aircraft. The mobile network frequencies specified in the radio license may be used for command and control links, payload connections or calls.

- **Use of private mobile network frequencies for aviation (needs regulation update)[155]**

Traficom may grant licenses but they do not support aviation cases very well.

  - B40 2.3 GHz is mainly meant for terrestrial use cases. For drone cases can get only 6 month licenses at a time
  - N258 24250-25100 is not meant for aeronautical use

- **Short-term test licenses are possible**

[155] P. Ojanen and S. Yrjölä, "Spectrum Regulation in the Airborne era: The Viewpoint of UAS-Based Services in 5G," 2021 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), 2021, pp. 228-236, doi: 10.1109/DySPAN53946.2021.9677385.

Traficom may grant short-term test licenses for tests and trials of RPA. Traficom assesses case-by-case whether a radio license may be granted for the requested frequencies

3.2.3 Greece

3.2.3.1 Greek UAV Regulation

Hellenic Civil Aviation Authority (HCAA) is responsible for authorizing Unmanned Aircraft Systems2 (UAS) flights in ATHINAI FIR / HELLAS UIR. It employs the UAS – Flight Regulation Support System (UAS-FRSS) system, that 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.

UAV flights are regulated in Greece by the following legislation that has come into force since 01.01.2017 and complemented in 2021 by EU regulation: 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)[156].

3.2.3.2 Greek Spectrum Regulation and Procedures

Considering the 5G licensed spectrum allocation in Greece, COSMOTE, as of December 2020 following the 5G auction carried out by the Greek NRA (National Regulation Authority) has been officially awarded the bands[157] [158] shown in Table 7. The other two operators in Greece, Vodafone (a) and Wind (b), have also secured (a) 140 MHz in the 3.4-3.8 GHz band, 20 MHz in the 700 MHz band, 400 MHz in the 26 GHz band and (b) 100 MHz in the 3.4-3.8 GHz band, 20 MHz in the 700 MHz band and 200 MHz in the 26 GHz band.

Table 7 Frequency Bands Allocated to COSMOTE

Frequency Band	Acquired Bandwidth (MHz)	UL Frequencies	DL Frequencies
700 MHz (FDD)	2 × 10	778 – 788 MHz	723 – 733 MHz
2100 MHz (FDD)	2 × 20	1960,3 – 1980,3 MHz	2150,3 – 2170,3 MHz
3400 – 3800 MHz (TDD)	150	3450 – 3500 MHz, 3500 – 3600 MHz	
26 GHz (TDD)	400	26700 - 27100 MHz	

[156] https://dagr.hcaa.gr/docs/HCAA%20UAS%20Regulation.pdf

[157] https://www.eett.gr/opencms/opencms/admin/News_new/news_1365.html

[158] https://www.cosmote.gr/cs/otegroup/en/cosmote_5g_auction_spectrum.html

In respect to the drones' regulation framework in Greece, the European Union regulations EU 2019/947 and EU 2019/945 are applicable[159]. According to the European Regulations, the drone is not required to be registered, but the operator of the drone must be registered in the field of operators of the UAS FRSS information system. There is no need for registration if the drone[160], [161]:

- weighs less than 250 g and does not have a camera or other sensor capable of detecting personal data, or,
- weighs less than 250 g, has a camera or other sensor, but is a toy.

Once the drone operator is registered, he will receive the "operating drone registration number" (the country's prefix: GRC and thirteen alphanumeric characters), which must be displayed on all drones he owns, including privately built ones. He must also upload the "exploiter registration number" (exploiter registration number + plus three (3) secret alphanumeric elements (which must be known only to him)) to the "remote identification system" of his drones (if they support this system).

Operators of drones for professional use or private use (when the drone has a MTOM of more than 4 kg) must submit a civil liability insurance against third parties for all the drones they own.

All drone operators – regardless of whether they fly drones for private or professional use or in the open category or in the special category – according to European regulations, must receive training for the category of drone they are going to use.

If a flight plan is required to be submitted, then the operator will first need to register with the YED (initially as a single operator) to obtain the three necessary Registration Numbers, referring to Owner Registration Number (AME), drone registration number (AMS), operator registration number (AMX) and set the also necessary DAGR access code.

[159] http://www.ypa.gr/en/HCAA_UAS_FLT_request_editable.pdf
[160] https://uas.hcaa.gr/Faq/Dagr#anchor4

[161] https://uas.hcaa.gr/RegistrationProcedures

4 5G TECHNOLOGY AND 5G!DRONES IMPACT IN UAVs MARKET AND BUSINESS – PERSPECTIVES AND RECOMMENDATIONS

This section identifies key application areas where 5G technology has been used providing new or enhanced services, and how each 5G!Drones stakeholder can benefit from these developments.

Nowadays, it is widely confirmed that the main technology that will accelerate the deployment of drones is 5G. 5G can be the catalyst and multiplier for the digital transformation of the UAV Market, enhancing the competitiveness of the EU economy and improving the quality of citizens' life. The Flight RB5 platform was introduced in August 2021 by Qualcomm[162], a major supplier of 5G chipsets, lowering the barrier to creating 5G-connected drones. Although the majority of current 5G applications concentrate on Ultra-Reliable Low Latency Communications (URLLC), 5G is also anticipated to offer edge Artificial Intelligence (AI), integration with satellite communication, inter-robot mesh or swarm communications, and most importantly, support for Beyond Visual Line of Sight (BVLOS).

In the US, the Federal Aviation Administration (FAA) granted permission to the Northeast UAS Airspace Integration Research Alliance (NUAIR) and the New York UAS Test Site in January 2022 to test and operate drones BVLOS throughout 35 miles of airspace in the New York Drone Corridor. At the same time, Verizon Robotics, the 5G communications service provider in the United States, has created software to integrate drones into American society. National Airspace System, which enables drones to work together safely and effectively. With a predicted CAGR of 47.03% between 2021 and 2028, the global market for 5G in aviation is expected to increase from USD 0.54 billion in 2021 to USD 9.92 billion in 2028 (Figure 59).

One of the businesses most severely damaged by the ongoing COVID-19 epidemic in 2020 was the aviation sector. The market growth has sharply declined as a result of important issues such as international travel limitations and a drop in aircraft deliveries. The market participants and service providers in the aviation business place a strong emphasis on the cutting-edge technology implemented for the sector's revitalization, such as 5G in the aviation market.

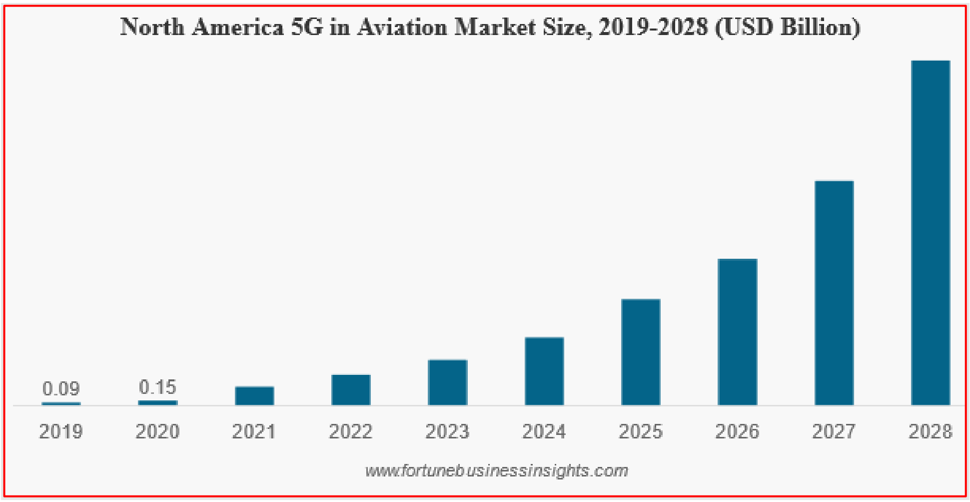

Figure 59: 5G in Aviation market

[162] https://www.qualcomm.com/news/onq/2021/08/qualcomm-flight-rb5-5g-platform-worlds-first-5g-and-ai-enabled-drone-platform

5G technology has the potential to effectively deliver real-time data to drones. The market is anticipated to expand as a result of rising demand for high-speed internet access for networking and communication between airports and aircraft.

There are three primary pillar categories of use cases that 5G networks are anticipated to support:

- **Enhanced mobile broadband (eMBB)**: Aiming to serve data-intensive use cases like virtual and augmented reality (V/AR), which demand high data rates across a large coverage area, is enhanced mobile broadband (eMBB).
- **Ultra-reliable and low-latency communications (URLLC)**: The goal of ultra-reliable and low-latency communications (URLLC) is to serve mission-critical applications that demand both ultra-high dependability and short delay, such as remote surgery, autonomous vehicles, and the tactile internet.
- **Massive machine-type communications (mMTC)**, which intends to connect a large number of power-limited devices with a variety of traffic profiles, such as those seen in the industrial Internet of Things (IoT).

Although some of the aforementioned scenarios have been thoroughly researched for terrestrial wireless networks, due to their significantly different operating environments, their methods and findings may not be directly transferable to future 3D wireless networks that include both UAVs (either as aerial users or as communication platforms) and ground users. Further importantly, they introduce new degrees of freedom for system design that haven't been fully explored but could improve communication performance even more.

For this reason, the experimentation planned and performed during the 5G!Drones projects, considering the various use-cases and the field trials performed at the 5G Platforms consisting the experimentation facilities of the projects, aimed primarily at assessing the 5G advances applicability in the UAV ecosystem. Such challenges were faced and properly resolved during the trials execution of the project, resulting in interesting findings and recommendations.

For example, offering these 5G services concurrently to ground users as well as UAVs presents additional technical difficulties that 5G!Drones field trials assessed by the real execution and realisation of the scenarios and use-cases identified in the project. For instance, because UAVs frequently fly at much higher altitudes than traditional terrestrial users, utilizing multiple antennas' high beamforming gain to provide eMBB service to UAVs necessitates that ground-based service providers (BSs) be able to steer the beam both in the azimuth and elevation planes. Therefore, the standard downtilted BS antennas, during the 5G!Drones trials needed to be modified because their initial setup only provided ground coverage.

The flexibility and openness to custom configurations offered by 5G platforms of 5G!Drones project, supported the execution of the trials with all the necessary customization needed for each use-case.

4.1 Overview of 5G platforms of 5G!Drones

In this section a brief overview of the four 5G experimental platforms used for 5G!Drones trials is presented. Detailed information on these platforms is available in the 5GDrones deliverables of WPs 2, 3 and 4[163].

4.1.1 5G!Drones 5G Platforms Technical Overview

EURECOM 5G facility (ICT-17 5G EVE)

The 5G facility of EUR, during the final trials, provided a full 5G SA connectivity. The 5G radio connectivity and access were based on Open Air Interface (OAI), an open-source implementation of a gNB running at FR1 frequency, more specifically band 40 (2300 MHz) using a 20 MHz of bandwidth. The RAN access was controlled using a RAN Intelligent Controller (RIC), following Open RAN specifications. RIC was used to collect RAN KPIs of the trials. The 5G Core Network is a service-based architecture implementing all key 3GPP 5G functions: AMF, SMF, AUSF, UDM, NRF, as well as NWDAF. The edge infrastructure uses a cluster of computing resources managed by OpenShift 4.9 Kubernetes container platform and benefits from technical support from REDHAT. The main cluster consists of 3 2x18-core Xeon Gold 6154 and 3 2x18-core Xeon Gold 6254 x86 servers (Dell R640).

The MANO layer is composed of a homemade Slice Orchestrator, NFVO, and VIM, allowing the deployment of network slices and services running VNFs and AppD using containers. The 5G facility of EUR has been improved to especially support 5G!Drones project, where different adaptations have been made to allow interfacing the 5G!Drones' LCM component. Indeed, an abstraction layer has been developed to translate LCM requests to a facility API, in order to deploy and instantiate a trial as well as collect KPI and redirect them to the monitoring module hosted by Frequentis. Moreover, the 5G facility web portal has been updated to interface with web portal 1 and the trial repository.

Athens 5GENESIS 5G facility

The 5GENESIS Athens platform where the final trial of UC4 Connectivity during Crowded Events took place, was supported by three different deployments, one based on 5G SA and two, an experimental and a commercial, 5G NSA systems.

The SA deployment was the Amarisoft Classic 5G SA Callbox combined with the Open5GENESIS experimentation suite, being capable in conjunction with 5G!Drones portal 1 to perform automated experimentation and KPI assessment. More specifically, this deployment supports 3GPP release 15 and FDD/TDD FR1 (< 6 GHz) with bandwidth up to 50 MHz and MIMO 4x4 in DL. All SSB/data subcarrier spacing combinations are supported together with mModulation schemes: Up to 256QAM in DL and 64QAM in UL.

This setup is also complimented by an edge computing deployment for low latency components, while the Katana Slice Manager is also supported, which is a centralised software component that provides an interface for creating, modifying, monitoring, and deleting slices across the cloud computing nodes of the infrastructure (I.e. Central cloud and Edge Cloud). Therefore, during a UAV flight, all the

[163] https://5gdrones.eu/deliverables/

virtualised components that are necessary for the flight are instantiated on a dedicated slice, reassuring the appropriate resource reservation for the needs of the experiment.

The 5GENESIS NSA deployment exhibited the mobile edge capabilities by implementing local-breakout for the traffic generated at the OTE Academy site. This implementation is based on Athonet's release 15 core network and a local break-out (S-GW) node at the OTE Academy site. The radio equipment was NOKIA Airscale eNB, gNB 2x2 MIMO, utilising 10 MHz at the 2.1 LTE band and 100 MHz in the 3.5 GHz 5G band.

Lastly, the commercial grade 5G NSA network was provided by partner COS as the third deployment option, utilised at the site of Egaleo. 5G!Drones traffic has been served through a specially provided mobile station (van) carrying all the necessary 4G and 5G radio equipment needed to deploy a 5G NSA cell on demand at a specific location. The key characteristics of the mobile station include an Ericsson 4480 eNB utilising 20 MHz at the 2.1 GHz LTE band with 4x4 MIMO antennas and .an Ericsson 4422 gNB utilising 100 MHz at the 3.5 GHz band with 4x4 MIMO antennas. At the transport layer, a dedicated mmWave optical link provided 2Gbps backhaul to the COSMOTE core located at a near (<10Km) distance.

AU – Aalto University 5G facility

The 5G facility of Aalto University is located at the Otaniemi campus of the university and covers an area of 5.2 Km2. As part of 5G!Drones project, the 5G facility of AU hosts two use cases (UC1SC3 and UC3SC2). The trial site of Aalto University operates a commercial gNB (Nokia AirScale gNB). The latter supports a functional split (RRU, DU, CU) and can operate in the two modes (NSA and SA). The gNB is deployed on the top of the Väre building and covers a wide area. In order to perform 5G tests, Aalto University has been granted by national regulatory authority, TRAFICOM, the license that covers a full 60 MHz band, from 3640 to 3700 MHz. The trial site of Aalto university also operates CMC core (Cumucore) which is a proprietary solution. The CMC core includes all the required functionality for interoperability with 3GPP Rel. 16 and has been tested with different RAN vendors. The current release follows a Service Based Architecture (SBA) and includes different network functions such as AMF, SMF, UPF, NSSF and NRF.

In the context of 5G!Drones project, the trial site of Aalto University has internally developed an edge platform. The latter allows the orchestration of vertical applications and also the monitoring of the related KPIs. Furthermore, the 5G facility of AU is hosting the majority of the developed modules in the project, including webportal1, LCM, the abstraction layer, etc. This allowed a complete integration of the 5G platform of AU with the 5G!Drones system.

5GTN – University of Oulu 5G facility

The 5GTN infrastructure from the University of Oulu provided the 5G Standalone (5G-SA) connectivity, 5G Non-Standalone (NSA) connectivity, and 4G connectivity during the project's final trials in Oulu. In the trials, the commercial handsets and Quectel modems have been used by the different partners as the User Equipment (UE).

The 5G-SA, NSA, and 4G access networks are based on commercial gNB and eNB using other frequency bands. 5GTN provides 5G-SA as well as NSA connectivity running at FR1 using the band n78 (3500 MHz, TDD) and a bandwidth of 60 MHz, while for 4G, it uses the bands B7 (2600 MHz, FDD) and B40 (2300 MHz, TDD) with the bandwidth of 10 MHz and 20 MHz respectively.

The 5GTN facility is composed of the open-source 5G core network Open5GS compatible with the 3GPP Rel.16 and has all the required Network Functions (NFs) of the Service Based Architecture (SBA) used for the 5G!Drones project. In addition, a commercial vEPC is used for the NSA setup and the 4G as an anchor network in the 5GTN facility. The edge infrastructure in 5GTN uses an ETSI-based commercial virtual Multi-access Edge Computing (vMEC) solution, which runs over the Kubernetes platform and Docker containers to host applications at the edge and is placed between the RAN and core network.

In the context of slice orchestration and management, the Open Source Mano (OSM) and the Virtual Infrastructure Manager (VIM), the MircoStack version of OpenStack, are used in the 5GTN facility. 5G!Drones' Web Portal 1 and 2, Abstraction Layer, and 5GTN Facility Adapter are placed in 5GTN infrastructure to conduct the trials. At the same time, the Life Cycle Manager (LCM) and Trial Enforcement are hosted at Aalto University, unlike the KPI monitoring hosted at Frequentis. Once a network slice and measurement job is created as part of the trial at the 5GTN facility, the Qosium tool collects the KPIs measurements from the UEs to then send them to the KPIC monitoring tool and Elasticsearch system hosted at Frequentis.

4.1.2 5G!Drones 5G platforms Performance Overview

An overview of the 5G!Drones 5G platforms performance is presented below for facilitating the analysis that follows in the next sections. Please note that analysis of the overall technical results, KPIs, trials, their evaluation and their technical impact is beyond the scope of this deliverable and are presented in WP4 deliverable D4.4.

EURECOM 5G facility (ICT-17 5G EVE)

The UC1SC1 trial is related to UTM and drone control over the 5G network. In this context, low latency is necessary between the UAVs and the UTM in order to avoid accidents and collision risks. To this end, the EURECOM facility has reduced latency to 3ms by reducing the TDD period (2.5ms), anticipating UL traffic (proactive scheduling), and using the Edge. As a result, the UC1SC1 trial was successful and demonstrated the impact of latency reduction on UAV control over the 5G network.

The UC2SC1 trial is related to public safety. It involves a drone that broadcasts video to firefighters on the ground. Therefore, it requires high throughput capacity and a good balance between Uplink (UL) and Downlink (DL) capabilities. To this end, EURECOM's facility uses a balanced TDD configuration, i.e., the same slot number for UL and DL. As a result, the UC2SC1 demonstration trials were successful and demonstrated the effectiveness of the facility in supporting bandwidth-intensive services and balancing UL and DL video flow. Indicative results are summarised in Table 8. More details are available in D4.4.

Table 8 Indicative UC2SC1 results summary

Video Quality	Average Throughput (Mbps)	Frame Round Trip Average / Max / Min (ms)
3840x2160	41,9	18.6 / 25 / 9
1920x1080	18,2	20.1 / 44 / 10
1280x720	10,6	20.01 / 91 / 10
640x480	6,9	20.2 / 29 / 7

Overall, the successful testing showed that the EURECOM facility improved the ICT-17 5GEVE platform by adding automation capabilities. Indeed, both UC1SC1 and UC2SC1 were automatically deployed in EURECOM Edge according to the ETSI MEC standard. As a result, the deployment time was less than 2 minutes. Moreover, the orchestration process is abstracted to 5G!Drones components via an abstraction layer on the top of the facility. In addition, Network-related KPIs are pushed to 5G!Drones KPI repository in real time to provide the UC owner with network and QoS information.

Athens 5GENESIS 5G facility

The UC4SC1 scenario is related to offering network connectivity to a group of people that are underserved or have no internet service when they are accessing their UEs. All this takes place with a drone capable of flying over to a specific area, at the edge of the 5G coverage, and having all the necessary equipment attached to it for maintaining a connection to the 5G network, while providing users with internet connection over a WiFi-6 network, which is deployed on the fly, utilizing a portable 5G CPE that is carried by the drone, which acts as moving/aerial relay node.

The successful variants of the trials did not only demonstrate the effective coverage extension of the 5G network, using UAVs as relay nodes – which is directly connected to the scenario scope – but also that it is possible to integrate components from distinct domains and combine different technologies. Furthermore, the use-case demonstrated that for IoT/sensor networks, a hybrid network architecture composed of high altitude UAV-BSs/relays and their ground counterparts is able to achieve wider ground coverage. In addition, UAV-enabled mobile data collectors can move close to IoT devices to collect data, such that their transmit energy is minimised. This is particularly beneficial in mMTC scenarios where connectivity and energy consumption are critical factors.

More specifically:

- 5G!Drones software components could easily be deployed and used on the 5G testbed being offered by the ICT-17 project 5GENESIS
- Vice versa, software components coming from the ICT-17 project 5GENESIS were easily installed and extensively used on hardware that was attached to UAV equipment in order to take measurements and conduct 5G experimentation
- Iterations of the experiments were made possible over both private 5G SA and commercial 5G NSA
- WiFi-6, the latest generation of publicly available WLAN technologies, which aims to enhance network capacity and performance as well, was successfully made to work together with 5G
- Critical Software deployed at the EDGE successfully performed mission uploads and waypoint flights of UAVs with Command-and-Control (C2) over 5G.

Finally, this use case was used also for leading the showcasing event at the Athens platform, where the project activities were opened to the public, inviting citizens to participate during the trial and test the 5G services offered by the relay node of the automated UAV. Moreover, this use-case proved also that UAVs can be used as platforms for aerial sensing to gather data in the sky. Due to its capacity for contactless, privacy-preserving item identification and environmental monitoring, radio-based sensing technologies have recently attracted more and more interest.

Even though radio-based sensing and radio-based communication systems have different guiding principles and goals, extensive research has been done to examine their coexistence, cooperation, and joint design, giving rise to a new paradigm known as joint communication and sensing (JCAS). This is so that both systems can utilize the same wireless infrastructure, RF technology, and spectrum without having to establish a separate wide-area sensing infrastructure, which also allows cellular networks reach their full potential without incurring the high construction expenses. Despite these alluring benefits, JCAS research in UAV communication networks is still in its infancy, and other intriguing and significant issues remain that need thorough examination, however 5G!Drones have proven in practice its feasibility.

AU – Aalto University 5G facility

The trial site of Aalto University hosts two use cases (UC1SC3: UAV logistics & UC3SC2: UAV-based IoT data collection). Several pre-trials have taken place in order to prepare for the final trials of the two use cases. The final trials have been conducted in August 2022 and have been disseminated via the social media of the project. Furthermore, the trial of the two use cases has been considered successful as it allowed to demonstrate that the 5G network is able to support these use cases. Further details on the results are available in D4.4. The following functionalities have been used in the final trials:

- A 5G network in SA mode,
- Edge computing capability to host the applications of the use cases,
- Trial controller modules,
- UTM support for the flights,
- KPIs monitoring tools to collect and visualize the KPIs captured during the trials

5GTN – University of Oulu 5G facility

During the project's final trials period in August 2022, six different use cases have been conducted at the University of Oulu 5GTN facility by the different partners. The tested use cases are as follows:

- UC1SC2: 3D mapping and supporting visualization/analysis software for UTM
- UC2SC3: UAV and video analytics for police tasks, including counter-UAS activities
- UC3SC1: SubSc1: 5G QoS measurements
- UC3SC1: SubSc2: Long range power line inspection
- UC3SC1: SubSc3: Inspection and search & recovery operations in large body of water
- UC3SC3: Location of UE in non-GPS environments

It is to be mentioned that to successfully conduct the final trials, different pre/technical trials have been performed by the partners in the 5GTN facility prior to the final trials. All the details of the final trials of the different use cases are available in the deliverable D4.4. The following components have been used during the final trials held in the 5GTN infrastructure:

- A complete 5G SA network
- 4G connectivity for heavy drone flights due to standing UAV regulations
- Edge computing (vMEC) for network slicing setup
- Trial controller modules for trial creation
- UTM support

- Qosium tool for network KPIs collection/visualization

The following table (Table 9) represents an example of the measurements done by Qosium tool at the 5GTN facility.

Table 9 Qosium tool at the 5GTN facility

Network Deployment Setup	Measurement Points	Height Above Ground Level – Drone	Video Generation Rate	Average Values measured by Qosium tool					
				Video Traffic Throughput (Mbps)	Delay of Video (ms)	Jitter of Video (ms)	Video Control Traffic (Mbps)	Delay of Video Control (ms)	Jitter of Video Control (ms)
5GTN SA	Nginx - Drone	Outdoor –25,6 meters	6 Mbps	6,489 Mbps	6,45	2,33	0,138	13,16	5,77

4.2 5G!Drones Business Impact to Use Case Areas

This section analyses the business impact that each 5G!Drones UC has created as perceived and analysed by core participating partners, depending on their business perspective and stakeholder category.

The content of the following sections is organised per UC and per core partners' stakeholder category.

4.2.1 UC1 UAV Traffic Management

The main purpose of UC1 was to investigate how to enable the BVLOS operation with the help of the 5G cellular network. To make it possible and safe, there must be a good understanding of the requirements from the UAV side and possibilities and limitations from the network side. During work performed in WP2, the UAV operators have specified the minimum set of the parameters required to describe the mission, which are necessary to obtain the flight permit. 5G infrastructure owners did the same from the network side. Finally, the set of the configuration parameters in the form of the high-level REST APIs was defined and implemented.

In WP3 the new enablers were proposed and built by 5G representatives and the UAV industry. As a result, it was possible to deploy and run the UAV applications in the MEC/EDGE and reduce the C2 latency and the amount of data, which needed to be sent to the central server owned by the UAV Operator.

UC1 showcased the international integration of two UTM systems and possibility for data exchange between them. In addition, the supplementary data feed subscription and delivery to the UTM was showcased.

4.2.1.1 5G providers/Telco operators

EUR partner

Within this use-case, EUR was able to show that C2 services link can be deployed and benefit from the low latency offered by the 5G infrastructure of the facility. Indeed, the RTT latency of a service running at the edge of the RAN was around 10 ms. In addition, this use case demonstrates the success of integrating ICT-19 trials on top of an existing ICT-17 platform (5G-EVE).

AU partner

The use case scenario UC1SC3 (UAV logistics) was trialled in the 5G facility of Aalto University. The success of this scenario has demonstrated that 5G (and telco operators) is able to support the challenging requirements needed to deliver cargos using drones. Indeed, in addition to C2 communication, a live HD video was also streamed from the drone to the UAV operator to monitor the operation in real time. Such a requirement was ensured thanks to the 5G network.

UO partner

Five out of the six use cases trialled in the UO 5GTN facility featured UAV Traffic management as a part of the operations. The success of the trials indicate 5G is very versatile in serving UAV operations. In addition to C2 operations all the trialled use cases had their particular applications of interest running. Integration of UTM and trial controller components to automate operations and post processing of the trials proved to be a viable approach for conducting operation with traceable evaluation of KPIs towards a specific operation plan.

4.2.1.2 UAV operators

INV partner

Thanks to the 5G!Drones project and UC1, INVOLI could further focus on product development for UAV Traffic Management and the future integration of the different users into the common, unsegregated airspace.

LEMAN Remote ID tracker was developed and commercially launched. It is fulfilling the ASTM standard F3411-19, ASD-STAN 4709-002 standard, EC Delegated Regulation 2019/945 and EU U-Space Regulation 2021/664, and has both types of Remote ID available: networked and broadcast. The owners of the legacy and DIY drones can buy it at an affordable price and adhere to the new legislation requirements, which are soon entering into the force.

The ADS-B, Mode A/C, Mode S and Flarm transponders receiver was further enhanced and the certification process was started. The improvements were mainly concerning the signal reception, implementation of the new metallic casing and involi.live web software. Additionally, the APIs for sharing the data towards the other systems were defined, implemented and tested. It’s now possible to share the live data from INVOLI server to the other UTM systems, like FRQ or DRR.

Web Portal and APIs for defining the Operational Flight Plan for any of 5G!Drones use case and scenario were designed, implemented, tested and presented to the public. They are fulfilling all the legal requirements defined for the U-Space and taking into consideration 5G configuration required for assuring connectivity between UAV and control software.

FRQ and DRR partners

The projects integration of two UTM systems (Droneradar and Frequentis) with the Trial infrastructure in 5G!Drones UC1 provided valuable experience and learnings (e.g., coordination on API functions, aligning standardised references (altitudes), agreement on status naming for operation plan planning workflows, etc.) to continue the development of the UTM products. Especially extending the importance of agreed and ideally standardised APIs and its interworking of the actual system behind regarding supporting more standards (e.g., different CRS and altitude systems, etc.), as well as clarifying API documentation, providing real world examples, and streamlining the integration experience is an important goal.

The solution showed that integration of UAV operators into the U-Space environment is possible and brings benefits (legal flights in controlled areas to enable additional business opportunities and use cases, improved situational awareness to enhance overall system safety) to all stakeholders.

CAF partner

During the UC1SC3 Logistics flight, CAFA used UgCS C2 (a containerised cloud native application that worked on a 5G edge server) which supported fully automated flight. The UAV operator uses the video stream from the drone camera over 5G network and uses the gamepad to conduct the landing of the drone to the Delivery Box. Video transmission and drone remote control takes place over a 5G network. During the flight the logistics drone location and telemetry was visible for other drone operators in FRQ and DRR UTM systems thanks to the integration with CAFA Tech GCS system GIP (Ground Control Station Integration Plugin).

The CAFA PX4 5G drone had an Intel Upcore computer on board, which enabled the efficient use of applications developed and tested on a PC. This is a big difference with other 5G drones on the market such as the Qualcomm/ModalAI 5G drone with ARM based processor which does not allow many applications to be installed easily. When using the CAFA PX4 5G drone, an important aspect was that the weight of the drone is less than 2kg, which is why its use in urban conditions is much easier according to EU regulations.

4.2.1.3 Academia/Research institution

EUR partner

The results collected during the trials of UC1SC1 will be used to understand the relation between the radio channel condition (RSRP, CQI, BLER) and the latency of the C2 link experienced by the drone. The results will be used to build a dataset and disseminated through scientific publication to the community.

AU partner

As an academic institution, AU has considered the use case scenario UC1SC3 to address a number of research challenges. Several scientific papers have been published by Aalto University, in international journals and conferences, that consider live video streaming and cargo delivery.

UO partner

UO partner, as UC1Sc2 contributing partner and extending the scope of 5G!Drones beyond the testing of UAVs in 5G, addressed a recommendation made by reviewers (period 1 review) for examining the **advantages and disadvantages of skycam (cabled drone)** utilisation in a 5G testing environment. So, using under the trials a skycam as replacement for drone testing, UO reached to the following reporting of skycam's advantages and disadvantages, as well as potential useful applications:

- Advantages
    - no need for flying license
    - can be used in no-fly zones

  - can be used above crowd
  - repeating tests with accurate movement and velocities
  - more accurate movement in different wind and rain conditions
  - repeating test flights without human supervision
  - higher payload, useful especially when prototypes of test equipment are heavier
  - silent if compared with drones
  - same route on every flight
  - cheaper in price / payload comparison
  - less power for same payload

- Disadvantages

  - set up of cable system
  - elasticity when using long cables
  - same route

- Useful applications

  - testing communication range and bandwidth in motion and different distances
  - testing sensors in different conditions
  - testing accuracy of position equipment (like GNSS)

4.2.2 UC2 Public Safety

4.2.2.1 5G providers/Telco operators

EUR partner

Like for UC1, UC2 use-case EUR was able to show that a high-bandwidth demanding service like MCS application can be deployed and run smoothly on top of the 5G infrastructure of the facility. Both UC1 and UC2 demonstrate the efficiency of using an Open-Source implementation and its capacity to fulfil commercial 5G services.

UO partner

Within UC2SC3, UAV and video analytics for police tasks, including counter-UAS activities showed a complex, fully automated UAV operation can be run over a 5G infrastructure. While fulfilling a functional service (counter-UAS), also communications network quality of service can be mapped and performance KPIs can be traced.

4.2.2.2 UAV operators

UMS partner

Thanks to the involvement in the UC2 UMS learnt precious lessons concerning the critical aspects of some network services used to better deployed the UAVs in some facilities (i.e. VPN). In terms of business impact this will enhance the requirement analysis to have a clear risk scenario and put in place the most efficient offer to the public safety stakeholders. Specifically, the knowledge we have gathered in regards to third party network systems have allowed us to streamline engagements with customers across two aspects:

1. The network questions that we need to send before project kick-off, as well as matching our requirements with customer capacities to assess any limitations and support for connecting the environment remotely and eventual privileged access to the host capabilities.
2. Modifying our systems to be more flexible in customer environments

Both are leading to shortening the timeline for technical validation, as well as easier pressure on tech by shortening the number of discussions pre-project-approval.

CAF partner

During the UC2SC3 Police flight, UgCS C2, a containerised cloud native application that operated on an edge server at Oulu University 5G, was deployed by CAFA during the UC2SC3 Police fly and supported completely automated flight. Additionally, the 5G edge server used by the VideoLyzer program allowed for low latency and reduced the requirement to broadcast all videofeed to centralised servers. Over the 5G network, video analytics were also conducted throughout. Due to the interface with CAFA Tech GCS system GIP (Ground Control Station Integration Plugin), other drone operators were able to see the drone's location and telemetry during the flight in FRQ and DRR UTM systems.

The Intel Upcore computer built into the CAFA PX4 5G drone allowed for the effective use of PC-developed and -tested software, such as video streaming and 5G QoS measurements. This is a significant distinction from other 5G drones already on the market, such as the Qualcomm/ModalAI 5G drone with an ARM-based processor that makes it difficult to install PC-based software. The CAFA PX4 5G drone's weight of less than 2 kg, which makes its operation in urban settings considerably simpler in accordance with EU rules, was a key consideration for using the device.

CAFA can use these technological solutions in the future when developing and offering its own drone services to customers.

4.2.2.3 Academia/Research institution

EUR partner

EURECOM will disseminate the trial results in OpenAirInterface (OAI) to prove the efficiency of the OAI software tool to support QoS demanding scenarios such as UC2SC1.

UO partner

The data obtained during the UAV operations enables UO to understand on deeper level what is required from a 5G network to efficiently serve complex, multi-application flying entities. The results steer the focus of future developments of the 5GTN facility.

4.2.3 UC3 Situational Awareness

4.2.3.1 5G providers/Telco operators

AU partner

The use case scenario UC3SC2 (UAV-based IoT data collection) was trialled in the 5G facility of Aalto University. The success of this scenario has demonstrated that 5G (and telecom operators) is able to support the challenging requirements needed to capture IoT services from the sky. Indeed, in addition to C2 communication, a stream of IoT data was sent from the drone to the UAV operator in real-time. Such a requirement was ensured thanks to the 5G network.

UO partner

Four use cases were trialled at the UO 5GTN facility. The success of the trials indicate 5G is very versatile in serving UAV operations. In addition to C2 operations all the trialled use cases had their particular applications of interest running. Integration of UTM and trial controller components to automate operations and post processing of the trials proved to be a viable approach for conducting operation with traceable evaluation of KPIs towards a specific operation plan. A noteworthy observation is the need to consider allocation of a higher fraction of uplink resources of the overall 5G bandwidth when performing many UAV operations. Many UAVs operations produce quite significant uplink traffic challenging the basic fractional distribution of uplink/downlink resources.

ORA partner

The use case scenario UC3SC1 (5G QoS measurements) was trialled at Bretigny-sur-Orges on Orange’s commercial 4G / 5G network, using the Morinant enabler. Results have shown that the actual performance of aerial connectivity for the considered radio environment is at least as good as it is on ground and definitely much better than simulation-based studies, with no obvious impact of handovers. Yet, more measurements in various conditions are needed for providing real assessments and a better integration of the Morinant enabler in UAV rather than using a smartphone is needed for collecting more measurement results.

4.2.3.2 UAV operators

ALE partner

Thanks to the addition to 5G within the Alerion hybrid drone, this solution will allow covering, and theoretically unlimited area to perform its mission, such as environmental monitoring and search and rescue in aquatic environments. Also, the 5G feature can be brought to other solutions bringing similar features for other drone technologies Alerion is developing, to benefit the end users.

AU partner

AU, as leader of UC3Sc2, tested the collection of IoT data from flying drones. Indeed, when equipped with the adequate IoT sensors, drones can collect and capture the related sensor measurements while flying. One of the key objectives of UC3SC2 is to demonstrate new business models from incorporating IoT and drones connected to 5G networks. Two models with an important business impact have been identified from the scenario led by Aalto University:

- IoT as a service: this reflects the case where a drone vertical gets a request to collect some IoT data from locations specified by a customer. A business contract is therefore established between the drone vertical and the customer. It has been demonstrated that 5G plays a key role especially in terms of providing a good coverage, allowing the drone to fly to the target location specified by the customer without losing connectivity, and ensuring enhanced connectivity to control the drone and transmit the collected data.
- Added-value IoT services: this reflects the case where drones collect different IoT data while performing their initial tasks. An illustrative example is when a drone is flying to deliver a cargo (main task) and capture different IoT data while flying (added-value). This model has an interesting business impact on the drone vertical, as it ensures added values (and revenues) on the top of the initial tasks. It has also been demonstrated 5G is playing a key role mainly in terms of providing enhanced connectivity and a wide coverage.

The discussion performed by AU (internally and with some partners) showed that different customers are interested in these business models. In particular, meteorological institutions are very interested in getting IoT data from flying drones. Such data will be used to ensure better weather forecasts as it includes data from the sky rather than old forecasting systems based on ground IoT data. On the other hand, these business models will be associated with a huge impact on UAV verticals, which is also empowered by the use of 5G as a communication infrastructure.

CAF partner

During the UC3SC1SSC1 5G QoS measurement and 3D mapping light, CAFA used CAFA 3D Analyzer and UgCS C2 (a containerised cloud native application that worked on Oulu University 5G edge server) which supported fully automated flight. CAFA 3D Analyzer is an application that displays 3D space as a point cloud which works in a common web browser, which allows flexibility to add various 3D measurement results. This will enable CAFA to continue to develop and offer services related to 3D analytics to customers.

4.2.3.3 Academia/Research institution

AU partner

As an academic institution, AU has considered the use case scenario UC3SC2 to address a number of research challenges. Several scientific papers have been published by Aalto University, in international journals and conferences, that consider UAVs equipped with IoT sensors and send data in real-time.

THA partner

5G!Drones business impact to Use Cases areas is for Thales not limited to only UC3 SA. Indeed, developments achieved can address a broad range of various domains from defence and security to Transport going through Aerospace. In view of activities led by Thales in each of these domains, 5G!Drones project results have been advertised and recognised by GBU SIX Business lines but also other GBU (e.g. AVS) as key to value to support the latest innovation and capabilities of Thales drones solutions (e.g. Drone Solutions | Thales Group[164]) in the specific context at hand.

5G!Drones project results are also seen as many enablers in support of AI at the edge, even extreme edge. As such, it opens alleys to explore distributed AI at the edge and has the potential to release fully new sets of intelligent apps and services while contributing to overall energy efficiency.

UO partner

The data obtained during the several UAV operations enables UO to understand on a deeper level on what is required from a 5G network to efficiently serve complex, multi-application flying entities. Especially research, how to efficiently manage UAV operations when a drone changes from 5G to 4G and back during single UAV operations needs to be investigated. The results steer the focus of future developments of the 5GTN facility.

4.2.4 UC4 Connectivity during Crowded Events

4.2.4.1 5G providers/Telco operators

[164] https://www.thalesgroup.com/en/markets/aerospace/drone-solutions

NCSRD, COS and INF partners

Telecom companies are in a great position to play a key role in the quickly expanding commercial drone market. Telecom operators are excellent candidates to provide drone-powered services for businesses due to their strengths in connection, cloud, big data, and analytics. Unmanned traffic management (UTM) solutions are one example, and operators are well-positioned for them since they have access to mobile networks. This new set of services will be possible thanks to secure, scalable, and high-quality connection for the drone market. According to analyst firm Markets and Markets, the global UTM market will generate $1.96 billion in sales by 2025.

There are three potential business impacts for cellular network integration with unmanned aerial vehicles:

- **UAV-Assisted Cellular Communication**: In their most basic form, UAVs function as flying base stations, relays, or localization anchors that may intelligently relocate themselves to help the current terrestrial wireless communication system enhance user experience (UX), spectrum efficiency, and coverage improvements. The incorporation of UAVs into the existing terrestrial communication system has various benefits due to their dynamic mobility and repositioning. An extremely tempting alternative for disaster management, search and rescue, or emergency response is the base station placed on the UAV (flying base station or relays). By carefully arranging flying base stations in 3D and coordinating their location to meet user demand in hotspot areas, it is possible to increase the coverage and data rate of current cellular networks. These advantages undoubtedly meet the varied, changing, and growing data demands in 5G/B5G cellular systems.
- **Cellular-Assisted UAV Communication:** In order to access the cellular network infrastructure from the air, flying UAVs are realised as new aerial User Equipment (UEs) that coexist with terrestrial UEs. Due to the efficient method for establishing dependable wireless connectivity with ground cellular stations, this paradigm has recently attracted a lot of interest.
- **UAV–UAV Communication**: According to this opportunity, a fleet of UAVs can cooperate with one another to avoid collisions and consistently communicate with one another while sharing the cellular spectrum with terrestrial users.

The Athens trials have proved that the performance characteristics of the existing 5G NR networks, both on latency and transfer rates, with careful planning even on the already deployed commercial 5G NSA networks, are adequate for the acceptable operation of 5G assisted UAV flights. What follows as a clear realisation is that the 3GPP Release 17 capabilities, when made available in commercial systems, will unveil the pioneering potentials of the UAV and Cellular networks tight interworking. Capabilities such as Location management, Group management, Configuration management, Identity management and Resource management are vital but still not inherently supported by the enterprise or the prototype mobile network products.

As extensively analysed in D5.5 on the final exploitation plans, as a first step, COSMOTE is already investing in employing its own fleet of UAVs for optimising the internal operational procedures to reduce OPEX. On this account, UAVs already have a transformational impact on the MNOs business practice and are expected to automate and resolve tedious tasks timely and cost effectively. On top COSMOTE is following closely the UAV vertical industry requirements to explore B2B investment opportunities, capitalising on the revolutionary impact of UAVs in the logistics and agricultural business. Employing UAVs for disaster recovery first responders' networks at rural locations and terrains outside vehicular reach is considered a unique solution. Nonetheless the practical utilisation of UAVs for high-density ad hoc hotspots is still considered a developing concept, that apart from technical improvements (such as reducing the cabling involved) need also address safety and regulatory constraints before standing as a true alternative of the mobile (van) base stations.

4.2.4.2 UAV operators

UMS partner

Unmanned life's core IP is the leading software platform for the seamless orchestration of autonomous robotics. We can deploy, control, and orchestrate at scale, integrated and hybrid swarms of different types of robotic devices (drones, AMRs, etc.) for industry 4.0 and smart cities sectors, with existing projects in emergency response, hybrid manufacturing, autonomous surveillance & more. Our unique connection and orchestration between robotic devices are interoperable across networks, meaning we can work across 4G and private LTE, but we leverage 5G to unlock the next step in automation, with high-speed, low-latency, and high-capacity networks creating value in robotic swarms.

As 5G is commercially rolled out, there are several challenges in connecting and applying these networks to maximise value. This phased rollout approach often means under-delivering on certain aspects of latency or bandwidth, which can represent a problem for mission-critical applications on our software platform.

For example, emergency response using drone swarms via our platform utilises network to:

- Command and control drones autonomously,
- Stream Live Video,
- Enable data flows for AI detection of the person of interest,
- Connect to a user interface for the first responders to view,
- Enable autonomous triggered drone response.

Although the platform has built in redundancy measures, losing or having a slow connection can decrease the response times of drones, as well as reduce the quality of certain features, which can have knock-on effects.

5G!Drones and UC4 had relevant impacts to Unmanned Life business considering the specific use case where we were involved. The most evident impact was in designing and deriving business documents related to the network requirements for commercial projects, in addition to driving technical tests, validations, and logging, for network requirements. These key points enable us to mitigate problems with the networks, and directly translate across to the work we are doing with the Telcos to deploy our solution globally. Therefore, 5G!Drones has shown the benefits of 5G's low-latency and high-bandwidth, alongside the necessary mitigation strategies that technology providers need to take in order to deploy at scale, especially in public safety scenarios, where these benefits are highlighted most due to the time constraints given in the vertical.

Applications in crowded environments such as the UC4 scenario we were involved in during the 5G!Drones project would be impacted in the following way:

- 70% faster response in incidence verification with the use of 5G Booster
- 3x faster response to get to a waypoint in crowded environments
- 66% reduction in employee time spent for surveillance tasks

The amazing numbers in the bullet point list above are a result of a relevant reduction of latency and delay at waypoint command tested in the UC4, while the last value is referred to the reduction in employee time we have already tested in other security verticals thanks to the application of the 5G network for UAV and that can be surely applied also to this case.

4.2.4.3 Academia/Research institution

NCSRD partner

The purpose of this scenario was to demonstrate how UAVs through 5G network capabilities can improve connectivity services in a highly crowded environment, e.g. during large events. To that end the capabilities of the scenario included autonomous flight planning and navigation (C2 over 5G), utilisation of 5G User Equipment (UE) to extend the coverage and provide ad-hoc connectivity to people, as well as signal strength measurements across the flight. Assume a ground BS is in contact with a ground user. A UAV using the decode-and-forward protocol is sent out to act as a wireless relay in order to provide dependable end-to-end communication and create a two-hop relaying system because there is significant shadowing in the direct channel. By concurrently optimizing the location of the UAV relay and the block lengths in the two hops, considering the necessity for end-to-end communication latency, it is usual practice to optimize the overall possible rate of the user.

Beyond the limits of realising the specific use-case of coverage extension with aerial-5G_CPEs and BSs, the successful execution of the trial also opens the path for further specialisation and additional research directions, creating additional impact in the 5G and UAV research field. Paying special attention to the recently developed cost-effective IRS. mmWave and IRS are more suited for short-range coverage, especially where there are strong deterministic channel components, like the LoS path, but M-MIMO_based BSs can be deployed for long-range coverage with huge devices. Unlike IRS, which employs passive reflecting elements, M-MIMO and mmWave both call for the deployment of active antenna arrays and typically have higher weight, hardware costs, and energy usage. Additionally, because IRS uses a passive reflection mechanism, it needs a larger aperture than M-MIMO and mmWave-based active arrays. This poses new business opportunities for the related passive IRS channel estimation, which in practice necessitates more installation space and could lead to a higher degree of computational complexity.

More specifically, the following market impact and business opportunities are created, considering future research directions:

- **MIMO and mmWave for UAV Communications**. The current 5G standard's M-MIMO, a crucial enabling technology, shows promise for facilitating cellular-connected UAV communications. With full-dimensional big arrays, ground BSs may perform fine-grained 3D beamforming to reduce interference between low-altitude terrestrial users and high-altitude UAVs, resulting in significantly improved network throughput.
- **IRS for UAV Communications**. Despite the promised benefits of M-MIMO and mmWave communications, their high complexity requirements, high hardware costs, and higher energy consumption are still major obstacles to their widespread use. A novel and affordable alternative to boost received power and reduce air-ground interference in 3D space is IRS, which has recently come into existence. In general, IRS can be mounted on UAVs to support terrestrial communications or installed on the ground to support UAV communications. The respective business opportunity and market impact that is raised by these research directions can be realised in the IoT business.

  In specific, a single UAV may be required to fly consecutively toward each IoT device or cluster in order to gather and disseminate data in IoT networks for high data rate transfer. However, this results in a higher energy consumption for UAV propulsion. Sending out numerous UAVs is one potential answer to these problems; however, this involves sophisticated UAV-UAV coordination, which raises operational costs and signalling overhead. Instead, a well implemented IRS can assist in resolving this problem. The high route loss between the UAV and other devices can then be efficiently compensated by utilizing the deployment of IRS, meaning that the UAV only needs to directly cover a portion of the IoT devices. Due to the restricted energy supply of IoT devices, this is especially helpful for uplink transmissions as it helps balance the energy trade-off in ground-to-UAV connections.

4.3 Overall 5G UAVs Market Perspectives-Challenges and Recommendations

One of 5G!Drones main goals was to give the impulse to the European industry and academic institutions to become the leaders for development of drone operations beyond line of sight, utilizing the novelties of 5G cellular networks. During the 3 and half years, 5G!Drones partners were working together and sharing knowledge from different disciplines to achieve defined objectives. Use of 4G networks for drone control and payload transmission, were good prognostic for faster and wider adoption of upcoming 5G services in the future. BVLOS flights will be boosted by enhancements brought by 5G gaining better suitability and focus to serve the needs of the end users.

This section of the deliverable puts together all concerns, challenges, perspectives and recommendations as perceived by the different partners from their own point of view and perspective.

4.3.1 Challenges for the 5G and UAVs Market Perspective

Given the experience gained from the 5G!Drones field trials and showcasing events, towards providing recommendations, we first identify the following well known challenges that impact the overall 5G-UAV market perspectives.

4.3.1.1 Challenges for the UAV Market Perspective

- Beyond Visual Line Of Sight Flights account for at least 60% of UAV potential (BVLOS). For these flights, the operator must obtain Air Traffic Control (ATC) clearance three to five days in advance, as well as permission from any local authorities or landowners if the flight is intended to pass over their property. There are no other UAVs or aircraft permitted to operate in the separated area where flights are conducted.
- The ratio of unmanned aerial vehicles (UAVs) to piloted aircraft is already 30:1. Current ATC systems lack sufficient functionality in conjunction with the UTM, cyber security, and capacity to manage a growing number of drones.
- Up to 90% of drones operate under solid mobile network coverage, allowing for identification and UAV traffic management (UTM), especially in heavily populated regions.
- In addition to other non-aviation infrastructure owners, mobile network companies may offer charging and unloading stations.
- The combination of current ATC systems, mobile and satellite networks, and autonomous traffic management platforms is the foundation for international projects on unmanned traffic management systems. Cooperation between aviation and telecommunications regulators and players is one of the main challenges.

4.3.1.2 Challenges for the 5G Market Perspective

- Numerous international investments and 5G pilots with uncertain business case yet, lacking of 5G Ecosystem suitable to support specific vertical industries, such as UAVs, in conjunction with the uncertainty about the vertical solutions business model among the value chain's key players
- Sectoral and user digital maturity is underdeveloped, e.g. considering the limited 4G penetration, resulting to businesses and operators with a low risk tolerance and short-term planning

- Dependence on third-party infrastructure or managed services, also given the competing technologies (NBIOT, WiFi 6, etc.) creates a blurred service cost (incl. taxation) and a difficulty to plan accordingly, given also the rise in electricity supply demand.
- Legal and regulatory challenges on modernising existing framework for small cells deployment, as well as the lack of an agile process for powering up new stations needed for unleashing the expected performance of the 5G system.
- Lack of a regulatory framework related to enabling technologies for special vertical use cases, such as UAVs and connected cars.
- Necessary development of 5G coverage to be able to successfully reach UAV corridors can lead to higher infrastructure and development costs, as network coverage is often targeted to serve ground users. This development is especially key, as ultra-low latency for autonomous control, and high bandwidth for real-time data transfers are a key value proposition with drones.

4.3.2 General 5G-UAV Market Recommendations and Future Pathways

In this section, 5G-UAV well known aspects and limitations are highlighted/addressed by recommendations and future pathways/proposals.

- **Demand creation of the 5G-UAV market.** Government should play the role of the market maker by taking initiatives on policy interventions. The EU should actively support policy and offer incentives to promote drone production and use. After making the necessary adjustments, several of the recently announced drone regulations ought to be adopted by all EU-members as best practices.
- **Facilitate UAV manufacturing and testing sites**. For facilitating EU-members to apply for the creation of testing sites, the EU should create a relevant policy framework and procedures. Utilize PPP methods to encourage private investments in the creation, management, and upkeep of the test sites. This action also includes the support of strategic partnerships on filling TRL gaps in UAV/5G research, UAV/5G design, UAV/5G manufacturing, and UAV/5G testing technology
- **Support Innovation.** To bridge the gap between prototype and production, set up a method for invention to be transformed into economically viable goods. Establish innovation and growth accelerators for local start-ups and intellectual property (IP) connected to drones.
- **Provision of testing PLMN IDs.** The 5G regulators should consider the sufficient provision of testing PLMN IDs in order to be feasible the trial and execution of UAV-flights that test specific technical challenges, such as PLMN handovers during roaming conditions over various mobile operators.
- **Energy Charging Efficiency.** Currently the main UAV communications scenario's bottleneck is energy consumption. The charging effectiveness and cutting-edge energy delivery technologies, including distributed multi-point WPT and energy beamforming using multiple antenna approaches, should be also further researched in order to increase the autonomy of UAV flights.
- **Provision of capacity in the right place.** UAV operations, especially multiple operations within the coverage area of a single 5G base station can seriously challenge uplink channel capacity. Application areas relying on real-time situation awareness, such as

LiDAR and ultra-high-definition video streaming in addition to C2 can quickly overwhelm the available uplink capacity of commercial networks that use uplink/downlink fractions heavily favouring downlink capacity. Hence the challenge is provisioning dynamically sufficient capacity resources for a number of airborne users whilst retaining uninterrupted, high-quality services to the bulk of users at ground level. The only chance to succeed is establishing the permanent cooperation between USSPs and NOPs, which will allow in the short and long term to provide support for UAV flights via the 5G network at the required quality level.

This collaboration will take place in different ways in the context of processes with different timescales: dynamic network management through the mechanisms of local adaptation of network capacity to the temporary local service demand (still to be developed) and opening the network control plane for unmanned aviation domain systems (via NEF); participation of NOPs in the processes of validation and approval of scheduled flights, allowing for the adaptation of flights to the network capabilities and pre-adaptation of the network configuration to the service needs of drones; exchange of information on long-term drone traffic forecasts on the basis of trend analyses performed by airspace managers with NOPs, which will allow the planning of network infrastructure expansion to be able to handle future demand.

- **Serving both aerial and ground-based users simultaneously.** Near-real time antenna beam steering will be a key technology to enable such service provisioning for both airborne and ground-based users. In many cases the base station coverage is targeted to serve ground-based users. As the antenna beams heights are typically not very tall, some active measures are needed to simultaneously support both aerial and ground-based users.
- **Implementation of 5G System functionalities that are fundamental for UAV traffic support in carrier-grade solutions and commercial 5G networks.** So far, almost all commercial 5G networks worldwide are NSA networks; therefore, network slicing is unavailable, thus ultra-reliability of network service with impact on air safety cannot be guaranteed. The networks claimed as 5G are in fact throughput-boosted LTE networks with common handling of any traffic. The popular work-around, i.e. local campus network with dedicated spectrum like those implemented in Industry 4.0, cannot be applied here. The question of integration of softwarsed 5G System architecture with virtualization/containerization frameworks and MEC still needs to be answered (overlapping management/orchestration functionalities in these frameworks, no standardised specification of 5G-CP – MEP interface *Naf* = *Mp2*). Exposure of mobile network mechanisms to the aviation domain, which satisfy the TS 22.125 requirements, should be provided by relevant carrier-grade network functions.
- **Ability to provide 5G terminals able to connect to more than one slice at the same time.** One of the most promising features of 5G that the project put forward is slicing (possibility of separating the radio channel into two parts that do not interfere with each other). Although we were able to implement this functionality on the base station side, we were unable to exploit its full extent due to the lack of compatible 5G terminals and modems. We really believe that when devices will be able to access this feature, 5G networks will show their true potential compared to 4G, because for now it is limited to more throughput and less latency. We will then have the possibility of setting up separate channels for C2 and data, which will make it possible to distance 4G in terms of possibilities.
- It may happen that in some countries, there will be **no MNO interested** in providing the services for UAS Operators. In this case, we should have some mechanisms to give the possibility to the new players to enter such a market, for example as the virtual MNO.

- The mechanisms for **information exchange between MNOs and UTM about 5G** cellular network coverage should be put in place, and maybe even standardised – see the example of ACJA document “Network Coverage Service Definition” specifying interface for data exchange between MNOs and UTMs. The existing document was created with 4G in mind.
- Recently it has been noticed that too many services and aspects of our lives are relying on satellite GNSS signals, which are sensitive to interference and spoofing or manipulation. The same is true for UAV operations. Taking advantage of 5G features, the necessity for the **development of a new, complementary positioning system based on 5G infrastructure** and signals, might be considered as a backup for GNSS.
- Further development and **rollout of temporary 5G stations**, using drones as described in UC4, can enable on-demand networks for connectivity in emergency response, or social events. Bundled services such as connectivity extension using drones promotes portability, extensibility and unlocks new revenue streams for telecommunications companies.

4.3.3 Consortium-driven 5G-UAV Market Recommendations and Future Pathways

The special value of the 5G!Drones project was the cooperation of experts in the fields of telecommunications and unmanned aviation. The 5G System, according to its current specification and if fully implemented, can leverage the UAS operation. There are, however, still certain challenges to be addressed, following the experience after the 5G!Drones trials during which certain limitations of the 5G system and UAV interaction were revealed in relation to the identified needs of the unmanned aviation.

Some of these challenges seem to be included/addressed in the 3GPP roadmap, other 5G-PPP projects activities or in partners’ certain business processes, but there are also several issues that should be included into the concerns of UAV support by the mobile networks and rest involved stakeholders.

This section provides insights of consortium-driven UAV market recommendations and future pathways, originating from partners participation in 5G!Drones, other related projects or from their business interaction with customers and various stakeholders.

It is also worth mentioning that many of these recommendations and future pathway proposals have been published in 5G!Drones papers and communicated through conferences and journals to the widest possible scientific audience and general public.

- **D2D link** to provide short-distance direct communication among all the UAV regardless of the PLMN to which they are attached. Such a way of communication is widely used in aviation for broadcasting of location/telemetry information. The direct UAV-UAV communication is also one of the main enablers for drone swarms. Its standardization is still ongoing within Release 18, named “5G Advanced”[165] .
- **UAV support in NR –** partial UAS support in 5G RAN has already been included up to Release 17 through some general purpose mechanisms (e.g., RAN slicing, NR MIMO, enhancements of

[165] 3GPP Release 18 Scope and Timeline https://www.3gpp.org/release18

NR positioning and coverage, etc.)[166], but the dedicated support of UAV in NR is only in the scope of Release 18[167].

- **Seamless edge applications context switching** (change of the edge cloud or server) – the mobile network should have an ability to predict a handover and then forward the application's context (e.g., GCS) to the relevant server hosting a target instance of the application, which will take over the activity. However, the context transfer can take much longer than the tolerable delay for latency-critical services (5G HarmoniseD Research and TrIals for serVice Evolution between EU and China (5G-DRIVE: Deliverable D4.4: Final Report of V2X Trials[168]), because of the standardised procedure[169] and aspects of virtualization[170]. The solution for this problem may be the control over the user context transfer by the application[171]. Nevertheless, there is still an unsolved problem of the integration of various architectural frameworks with functional overlap between them, risking with uncoordinated competition of overlapping mechanisms (e.g., 5GS, virtualization, and edge computing frameworks)[172].
- **Lack of mechanisms for proactive coverage improvements on demand** – there are no interfaces exposed by PLMN to serve the requests for coverage improvements in the specific area, e.g., by UTM during the flight execution. With dedicated RAN controllers, such as O-RAN that enable the deployment of applications dedicated to RAN optimization, such mechanisms might be offered. The examples of UAS-oriented applications proposed by the O-RAN Alliance are flight path-based UAV resource allocation, radio resources allocation for UAV applications, massive MIMO optimization (e.g., for adaptive beam management to follow UAV swarm), etc. The generic O-RAN application template enables also a free extension of RAN controller functions (e.g., by APIs exposure). Due to the lack of 5GS and O-RAN integration, such systems cooperation is still problematic, but there may exist a potential proposal of solution of this issue[173].
- **Internal roaming for UAS support** – coverage problems in a specific PLMN could be solved by allowing UAV reconnection to any PLMN providing the best QoS in the area of concern.
- **Cross-border and roaming operations** – according to the EU rules of “Single European sky” (UAV can operate in any EU country, regardless of the country of registration and pilot certification) as well as “free movement of goods and services”, low latency services (e.g. FPV 20 ms to avoid cybersickness) in roaming will be demanded. UAV in roaming may require safe and dedicated communication channels both within the country of operation and to the home

[166] 3GPP Release 17 Scope and Timeline. Available online: https://www.3gpp.org/release-17]

[167] 3GPP Release 18 Scope and Timeline. Available online: https://www.3gpp.org/release18

[168] https://5g-drive.eu/wp-content/uploads/2021/08/5GD-D4.4_Final-report-of-V2X-trials.pdf]

[169] ETSI. ETSI GS MEC 021 V2.1.1; Multi-Access Edge Computing (MEC); Application Mobility Service API. European Telecommunications Standards Institute: Sophia Antipolis, France, 2020

[170] Sollfrank, M.; Loch, F.; Denteneer, S.; Vogel-Heuser, B. Evaluating Docker for Lightweight Virtualization of Distributed and Time-Sensitive Applications in Industrial Automation. IEEE Trans. Ind. Inform. 2021, 17, 3566–3576. https://doi.org/10.1109/TII.2020.3022843

[171] 5G-DRIVE: Deliverable D4.4: Final Report
of V2X Trials. Available online: https://5g-drive.eu/wp-content/uploads/2021/08/5GD-D4.4_Final-report-of-V2X-trials.pdf]

[172] Tomaszewski, L.; Kukliński, S.; Kołakowski, R. A New Approach to 5G and MEC Integration. Artificial Intelligence Applications and Innovations. In Proceedings of the AIAI 2020 IFIP WG 12.5 International Workshops, Neos Marmaras, Greece, 5–7 June 2020; Maglogiannis, I.; Iliadis, L.; Pimenidis, E., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 15–24. https://doi.org/10.1007/978-3-030-49190-1_2

[173] Kukliński, S.; Tomaszewski, L.; Kołakowski, R. On O-RAN, MEC, SON and Network Slicing integration. In Proceedings of the 2020 IEEE Globecom Workshops (GC Wkshps), Taipei, Taiwan, 7–11 December 2020, pp. 1–6. https://doi.org/10.1109/GCWkshps50303.2020.9367527

country. The Local Break-Out (LBO) roaming architecture (alone or hybrid with Home-Routed for some transmission channels) will have to be implemented based on the network slicing and differentiation of User Plane Functions for different channels.

So far, LBO has been practically unused (in 5G and earlier generations) due to the problem of home PLMN to verify the reported charging information about the usage of data transmission in visited PLMN. There is a specific problem of cross-border flights, where the continuity of flight control/traffic management, exchange of geofencing tokens, etc., must take place while simultaneously changing (re-selecting and re-registering) the area-specific UTM and PLMN. These questions have been raised by the 5G!Drones project and the solutions have been proposed[174], but they are still outside of the scope of the standardization.

- **Integrated UTM and PLMN interconnect architecture** – for deep integration of UTM and PLMN, especially resulting with joint authentication and authorization procedures (UUAA-MM, UUAA-SM) an effective interconnect architecture has to be developed. In the case of national roaming, the scale of direct interactions between different UTMs and PLMNs operating in the same area is not that big. In the case of international roaming of UAV, the interactions between visited and home UTMs/PLMNs will appear, hence the scale of potential bilateral interactions will become unmanageable[175]. The E2E joint authentication and authorization procedures involving all actors, both serving and certifying the identity and authorization should be agreed between the UAS and telecommunications Standards Developing Organizations (SDOs) to optimize the interconnect architecture.
- **Lack of E2E security mechanisms** – There is a rich set of security mechanisms in the 5G System to be used for data ciphering, integrity protection, or authentication of nodes and UEs. Secure interactions with other PLMNs and secure integration of non-3GPP access are also possible. However, these 5G System security mechanisms cannot be extended beyond the N6 interface for interconnection with an external Data Network (DN). The partial solution is proposed, but there is still a need to define a generic mechanism for harmonizing security with external data networks and service platforms.
- **Lack of real E2E slices** – the QoS and security control mechanisms (non-repudiation of data, data integrity, confidentiality of identities) are limited to the User Plane Function (UPF) span in the PLMN only, i.e. between the UE and the N6 interface. This problem is particularly important in the case of low latency and critical communication, such as C2, where the QoS violation impacts the safety of UAV operations. To maintain full control over transmission performance and security and thus mitigate the risks, PLMN should span up to the USSP services' hosting environment or host the USSP services in the PLMN's premises.

In addition, specific partners have provided certain recommendations as they originate from their business activities, with focus on how the UAV industry can be further advanced taking into account new emerging technologies such as 5G.

In specific, looking at the recent exits and several overtakes of known players in the UAV industry, it is justified to make the conclusion that the industry is still in an early stage of the development and that processes are not advancing at the fast pace it was expected. Recent announcements about takeover of AirMap by much smaller DroneUp (in partnership with Walmart), shutdown of Skyward owned by Verizon and taking over the drone delivery business activities by Matternet from the Swiss Post are the most spectacular. They show that the big players, whatever it is the telecom or the logistics industry,

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[174] Tomaszewski, L.; Kołakowski, R.; Korzec, P. On 5G Support of Cross-Border UAV Operations. In Proceedings of the 2020 IEEE International Conference on Communications Workshops (ICC Workshops), Dublin, Ireland, 7–11 June 2020; pp. 1–6.

[175] **https://doi.org/10.1109/ICCWorkshops49005.2020.9145262**

are losing patience and prefer for the moment to stay away and not engage themselves in the ongoing developments. This is probably discouraging other investors. There is a hope that the situation will change for the better after entering into force the new legislation in Europe and US. This will create stable and clear conditions for planning, obtaining the permits and executing advanced drone operations.

These fluctuations show that, despite positive thinking and conviction that drones are the future in many fields, it is difficult to build a business model driven on regulation and legislation, which is still being forged. Anticipating what could be needed or possible, instead of looking at real customer needs and pains is very often misleading.

INVOLI partner next steps are aiming at balancing between innovation following the customer needs and staying up to date and including in its products and services legislation and standardization trends. Thanks to this approach, it was possible to expand INVOLI's commercial offer, reinforce the development team and strengthen the marketing efforts. As a Supplemental Data Service Provider, INVOLI is not directly relying on 5G services availability, but it's believed that 5G will boost and accelerate the UAV market in general, which will increase necessity for INVOLI's products and services.

In addition, key feature pathways will originate from the air navigation service providers, U-Space service providers and supplementary data providers as expected by Frequentism partner. In specific, the European U-Space regulation provides some guidance on how different stakeholders are jointly providing the UAV environment. Derived from this, there are different points of view on market perspectives and business opportunities. Air Navigation Service Providers (ANSPs) are positioning themselves to keep control in the early stages of development and are providing funding for overall UTM solutions. Therefore, today it appears that U-Space Service Providers (USSPs) see ANSPs as their main growth lever. However, U-space is planned to be a free market where USSPs can freely compete, to the benefit of the drone operators. Different types of business models are foreseen from the USSP view:

- Drone operators pay USSPs for services used (including supplementary services)
- ANSPs subsidize the development and deployment of U-space services
- USSPs pay a "concession right" to ANSPs

For operations in controlled airspace, ATM stakeholders need to maintain digital situational awareness of drone operations and need to coordinate with the UTM stakeholders. The nature and frequency of rapidly changing drone operations in a dense airspace is very difficult for a human to try to overview and control manually. Mobile network connectivity is a huge enabler in this area.

Several services are needed for mission planning:

- Digital, 3D or even 4D communication network service level "coverage" data are needed
- Up to date ground risk data, including population density and ground obstacles are needed

U-space and digital airspace management is needed to support scalable growth of operators offering BVLOS services. The core purpose of U-space is to enable access to the airspace for a large number of drones. To achieve that:

- All flights operating in the proximity of drones need to be digitally conspicuous
- All aircraft need to be able to share information digitally during all phases of flight
- Separation needs to build on both strategic and tactical deconfliction, with conflict resolution presented digitally to all actors.

To support all these needs, Supplementary Data Service Providers need to be integrated in the U-Space environment. Mobile Network Operators, especially, can provide valuable information, as well as act as required enablers for UAV operations. C2 connectivity, mobile network coverage information, population density, remote identification, are just a few important examples.

Supplementary data providers, U-Space Service Providers, Air Navigation Service Providers – all of them can position themselves to be required in providing the necessary services – this opens various possibilities for business opportunities in present as well as in the upcoming years.

Another important aspect raised as concern by many partners acting as UAV hardware providers is the issue of component compatibility between UAVs and new technologies such as 5G. **Unmanned Life partner** will go on making steady efforts to enlarge the compatibility of its products with the other existing solutions in order to assure effective operation in all the complex situations it is possible to encounter in the public safety scenarios. This strategy will help to keep a competitive advantage which will allow UM: to gain a larger share of the UAV services market. 5G represents a fundamental substrate where the added value created by a wider compatibility will be able to make the difference.

Similarly, aspects related to UAV autonomy, range improvement, and reduced latency of signals exchange have been taken under consideration by many 5G!Drones partners. Drone applications needing more autonomy or range can be enhanced by using 5G technology, but not all applications need 5G or a mobile network. The use of these technologies will depend on diverse elements from regulation to 5G network access, and, of course, the need of this technology for the benefit of the mission.

Search and rescue, as well as environmental monitoring will have an advantage by using 5G networks, thanks to the increased range provided with ultra-low latency, high-speed broadband, and MEC capabilities. **ALERION partner** will work on including 5G capabilities to its development following the needs of its clients and the benefice of the missions. It will allow ALE to extend its commercial offer to drone solutions with 5G technologies thanks to the know-how acquired. It will help keep a competitive advantage, and allow gain a large share of the development of UAV solutions.

The **Aalto University partner** has presented the proof of concept for Follow-Me Edge solution, which moves the UAV pilot software, following the mobility of the UAV across the bigger area and multiple gNBs. This is a concept, allowing to reduce the latency of the signals exchanged between drone and UAV pilot software at any location. gNBs are grouped to the clusters, according to their geographical location and served by one edge server per cluster. The live migration happens when the drone is crossing the area covered by one Edge server and enters another one. Service works without interruption and the latency is maintained low, despite the mobility of the UAV.

Throughout 5G!Drones duration, **UAV industry partners** learned about the new opportunities brought by 5G services, which are well suited for the use cases of UAV systems operators. As one of the main achievements in this domain, it can be also reported the exchange of the UAV traffic and temporary traffic restrictions data between two European UTM systems. This is proof, that the future UTM can be built as a federated service, rather than a centralised, nationwide system. To do this, it was necessary to define the information elements, which need to be exchanged and to make necessary adoptions.

4.4 Future Research Opportunities with Business Potential

Despite the potential of combining UAVs with 5G techniques, the research on UAV-assisted wireless networks is still in an early stage and many open issues are in need of further research. In this section, we focus on the new opportunities in emerging network architecture and highlight potentially interesting research topics for future directions.

- **UAV-to-UAV and Satellite-to-UAV Communications**

A swarm of UAVs creates a multihop network to assist the ground wireless devices in sending and picking up packets, each of which has a trajectory, in order to offer communication service to them over a significantly large area. However, the link connection with the nearby UAVs is frequently lost due to the high-speed mobility and the requirement to maintain close communication ties with ground users. All conventional routing protocols cannot function well in FANETs in this situation[176]. Therefore, one challenging direction is how to manage the UAVs' flying in order to achieve effective service. Additionally, collision avoidance becomes a crucial development for the safe operation of many UAVs. Modern satellite-to-UAV channel models, however, don't include comprehensive propagation effects. The exploitation of channel propagation models for satellite-to-UAV communications is still in its infancy and remains a topic for future research.

- **Synergy of UAVs and IoT systems**
  A concept that was first suggested by Gharibi et al[177], is the Internet of UAVs (IoUAVs). It proposes that UAVs and existing IoT should be integrated dynamically. IoUAVs are a promising solution to realize the framework of a future IoT ecosystem where humans, UAVs, and IoT devices interact cooperatively. This enables ubiquitous information sharing and fine-granularity coordination among a fleet of UAVs due to the distinct characteristics, such as fast deployment, easy programmability, fully controllable mobility, and scalability. Even though IoUAVs have enormous potential advantages, their endurance and reliability performance are fundamentally constrained by their maximum battery capacity, which is typically low due to actual battery swapping restrictions (need for battery changes, conducted with human assistance or automatically, following several charging techniques, etc.)[178].

  On the other hand, IoUAVs need to use more energy to enable mobility and prevent collisions. This additional energy consumption, which is typically several orders of magnitude larger than the energy consumed for data delivery, depends on trajectory fluctuations in the timeframe of seconds, especially in industrial IoUAVs. It is therefore not simple to develop an energy-aware synergy between UAV and IoT system viewpoints. Exploiting the synergy between user mobility and UAV mobility is another important consideration for boosting wireless networks' productivity and profitability[179]. The convergence of IoT and UAVs also represents a completely unexplored area of future technology with the potential to fundamentally alter how we live today.

- **Security and Privacy**
  The open linkages and dynamic topologies that intentionally jam or disrupt a mission-critical area expose the integrated network to malicious attacks. Security is crucial in UAV-assisted networks because UAVs are always unattended and can be easily captured or attacked. A safe and lightweight system is required to protect against attacks like eavesdropping, man-in-the-middle attacks, and others in order to avoid malicious alterations. A zero-sum network interdiction game was recommended to capture the cyber-physical security threats in UAV

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[176] Bin Li, Zesong Fei, Yan Zhang, UAV Communications for 5G and Beyond: Recent Advances and Future Trends, IEEE Internet of Things journal, DOI 10.1109/JIOT.2018.2887086

[177] M. Gharibi, R. Boutaba, and S. L. Waslander, "Internet of drones," IEEE Access, vol. 4, pp. 1148–1162

[178] **https://www.mdpi.com/2072-666X/13/6/977**

[179] I. Bor-Yaliniz, A. El-Keyi, and H. Yanikomeroglu, "Spatial configuration of agile wireless networks with drone-BSs and user-in-the-loop," IEEE Trans. Wireless Commun., Early Access, **https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8506622**

delivery systems, while artificial intelligence solutions for cellular connected UAV application use cases were also suggested[180].
Overall, it is critical to protect SDN controllers from various cyber-attacks where the adversaries are able to wiretap the data and control signals transmitted through the radio links of the UAV systems. In the large coverage area of space-air-ground integrated networks, SDN controllers are responsible for managing resources and controlling network operation. In order to defend against harmful cyberattacks, timely methods and counter-mechanisms must be designed.

- **Interaction of Different Segments**
  How to utilize cutting-edge methods to guarantee seamless integration between the space-based network, the air-based network, and the ground cellular network is a key challenge for the integrated space-air-ground network. In order to ensure link reliability, it is important to create some cooperative incentives across distinct segments and specific cross-layer protocol designs are required. To achieve the seamless information exchange and data transfer among heterogeneous networks, it is necessary to provide scalable and flexible interfaces for these segments to connect and collaborate in such a complex network environment. For instance, the increasing variety of services may require UAVs to be the gateways between different networks, it is crucial in such a complex network to design interworking mechanisms for ensuring link reliability[181].
- **Space-Air-Ground Integrated Vehicular Networks**
  By integrating space, air, and ground communications into vehicular networks, it is possible to increase infrastructure coverage, use unmanned aerial vehicles to collect network information in densely populated areas, and offer high data rates for vehicle users in urban and suburban areas via ground networks and satellite networks, respectively. In order to effectively improve the system performance, the idea proposed is for a UAV-assisted framework to integrate UAVs with ground vehicular networks[182]. The increased mobility of satellites and unmanned aerial vehicles (UAVs) would constantly alter the propagation channel state in terms of free space path loss and Doppler effect. Effectively designed network architecture is needed to address the challenges with how vehicular networks and space-air-ground networks interconnect. Further, a comprehensive control mechanism coordinating the spectrum allocation, link scheduling, and protocol design for the space-air-ground propagation channel needs to be taken into consideration in order to support the data delivery with low latency and high reliability.
- **Energy Charging Efficiency**
  Any UAV communications scenario's bottleneck is energy consumption. Energy harvesting is utilised to increase flight times by exploiting green energy sources, as seen in recent improvements in battery technology like improved lithium-ion batteries and hydrogen fuel cells (such as solar energy). However, due to longer distance and random energy arrivals, the efficiency of energy harvesting is significantly lower. Novel energy-delivery systems, such as

[180] U. Challita, A. Ferdowsi, M. Chen, and W. Saad, “Artificial intelligence for wireless connectivity and security of cellular connected
UAVs,” arXiv preprint arXiv:1804.05348

[181] Bin Li, Zesong Fei, Yan Zhang, UAV Communications for 5G and Beyond: Recent Advances and Future Trends, IEEE Internet of Things journal, DOI 10.1109/JIOT.2018.2887086

[182] W. Shi, H. Zhou, J. Li, W. Xu, N. Zhang, and X. Shen, “Drone assisted vehicular networks: Architecture, challenges and opportunities,” IEEE Network, vol. 32, no. 3, pp. 130–137, 2020

distributed multi-point WPT and energy beamforming using multi-antenna approaches, are of immense interest to increase charging efficiency[183].

- **Closing the service gaps in 5G cellular networks for further improving UAVs benefits** Mobile networks are expected to be omnipresent, as reliable as possible and can be considered as the best solution for communication between the ground control station and the drone. However, cellular networks also have their limitations and pains. The nature of the problem can be of several kinds: the weak coverage or no coverage at all, bad signal quality due to interference, even if the signal is relatively strong, configuration error (no defined relations to handoff the connection from one base station to another), the temporary lack of capacity to handle the connection are the most common problems, which can occur. Usually, they will cause the connection to be interrupted and in the best scenario, the connection will be re-established in the interval of a few seconds. However sometimes the UE or modem can experience the more severe troubles, which can last for minutes. During this period, the drone can fly quite a long distance without the possibility of modifying its programmed trajectory nor even tracking its position.

  To handle this situation, it is possible to use the remote ID broadcast feature, which is defined as the mandatory drone identification. It means that any drone, which wants to fly in the EU airspace must be equipped with the device broadcasting locally the basic information to identify the drone, its actual position, heading and speed. The range of such a broadcast should be at least 500m, but if the receiver is specially designed, it can reach even 2-3 km. In fact, the range will depend on the density of interfering signals and the receiver's antenna position.

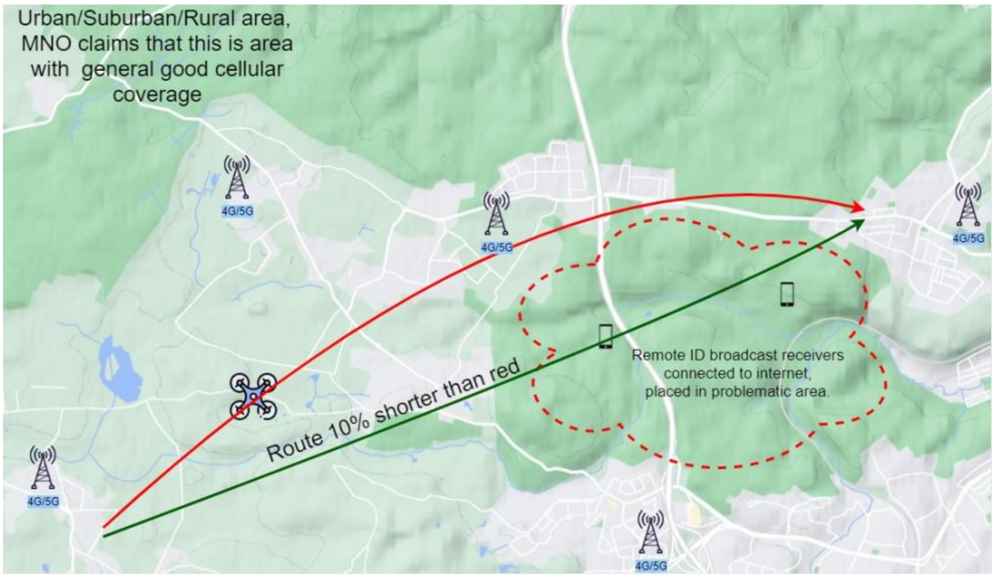

Figure 60: Remote broadcast receivers connected to internet can shorten the flight path[184]

Figure 60 above shows one of the use cases, where a remote ID receiver can bring some benefit. Such a small and inexpensive device with internet connection, installed in the place where the network problems occur consistently, would provide an alternative source of data

[183] Bin Li, Zesong Fei, Yan Zhang, UAV Communications for 5G and Beyond: Recent Advances and Future Trends, IEEE Internet of Things journal, DOI 10.1109/JIOT.2018.2887086

[184] https://www.alliedmarketresearch.com/drone-inspection-and-monitoring-market-A14422

about drone to the UAS operator and USSP. In the simplest form, it would assure continuous tracking of the drone in the moment of its connectivity problem – lack of cellular coverage. Of course, this solution will work only with the autonomous drone, which has a predefined route and only requires the supervision and modification of the route in case of emergency. It will not be suitable for "direct stick steering", because when you lose the connectivity, you will completely lose the control.

One may consider that such device does not only receive and forwards to the UAS operation centre the received broadcast messages, but can also communicate towards the drone, as the remote Ground Control Station. This would allow not only tracking the drone, but also interacting with it and modifying its parameters.

Such a solution for UAV has some similarities to the Femtocells concept developed by 3GPP, which can be installed in the places where the mobile network coverage is weak or not present at all. It can be interesting for drone operators and mobile network operators. The first can be interested in minimizing the risks during operation or reducing the time to reach destination by flying the shortest path. The second can be interested in fulfilling their service level agreement in the places where they have the problems with expansion or optimization of the network. The installation can be placed temporarily, just for assuring the safety for a short time, or can be permanent, if operations are carried out regularly in the area. It's possible that such equipment is managed and installed by a single UAS operator and that it's in the hands of the mobile network owner, who provides the service to multiple customers.

The cost of such hardware should be comparable to the cost of the mid-segment mobile phone or the router. It should be able to detect broadcast messages from drones and forward them further to the UTM or ground control station controlling the given device. At this end, this information would replace the data missing due to cellular connectivity problems. This will give the visibility for UTM and operators about mission progress, until the moment when the usual communication is restored. The receiver can be owned and managed by MNO, UAS operator or USSP, depending on the interest of any of them. It can be mounted in the permanent location or moved depending on actual need.

It's possible to give following benefits of such solution:

1. No need to stretch the drone route, to be always in the cellular network coverage – drone can fly the shortest path (battery and time savings)
2. The position of the drone can be always monitored, even if cellular communication is temporarily lost
3. MNOs can meet the SLA in the area, where usually they would encounter the problem, with the little effort and cost
4. The UAS operator can meet the imposed requirements for drone supervision, even in the area of problematic cellular coverage
5. In the case the device is able to act as the remote GCS, the UAS operator gains the control of its assets during the cellular connectivity outage. This allows the modification of the current flight plan, even during cellular connection problems and increases the overall safety of the drone operation.

To sum up, the deployment of 5G for UAV control is based on six pillars. This approach, based on six pillars, has been used in the 5G!Drones project since May 2020, when the IMT (Innovation Management

Team) of the project introduced it and then made an overview/update of this evolution at every plenary meeting. The Evolution of 5G drones in Europe 2021-2026 is summarised in Figure 61 below.

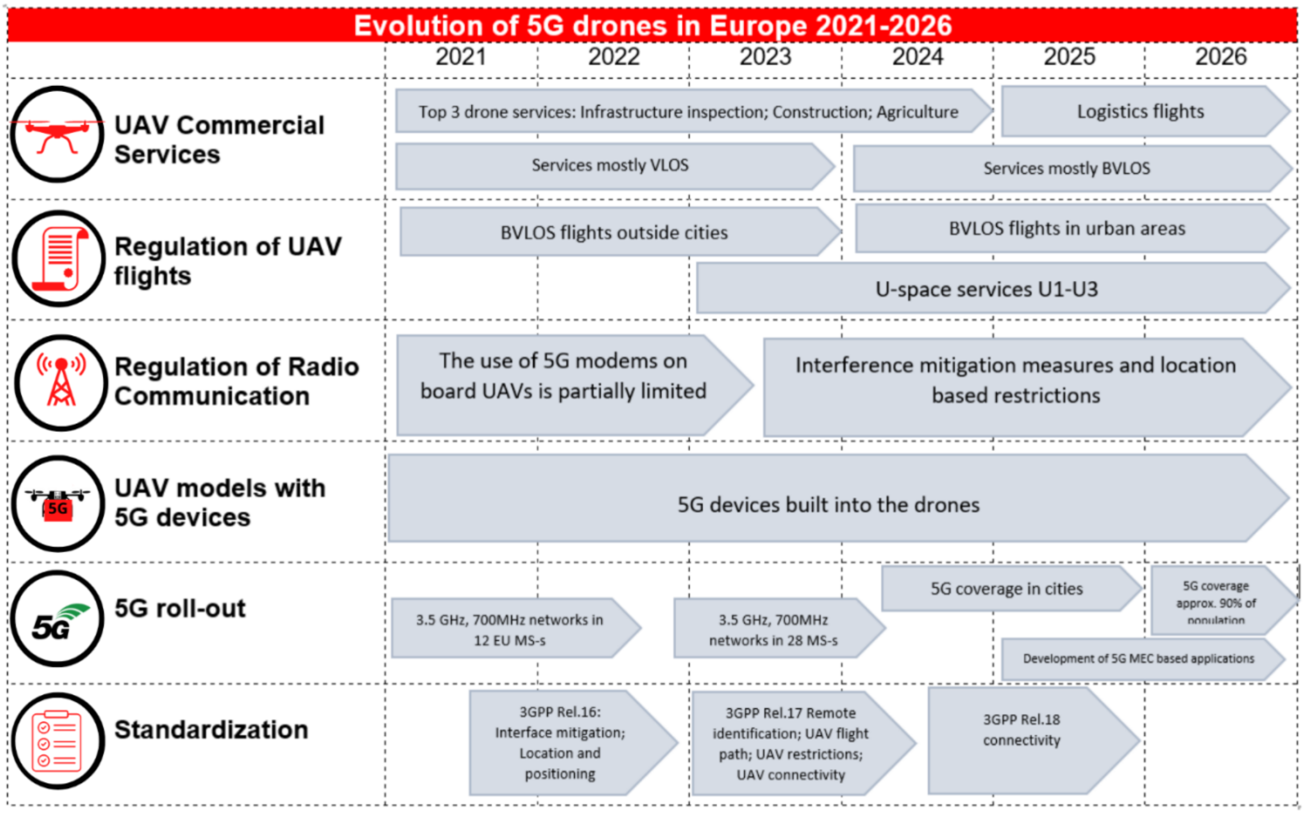

Figure 61 Evolution of 5G drones in Europe 2021-2026

Concerning the first pillar - UAV Commercial Services, it is important to note that, although there are high expectations for drone logistics, mass deployment is not expected before 2027, mainly due to regulatory restrictions. Therefore, drones and drone services related to Infrastructure Inspection, Construction Sector and Agriculture constitute the largest market shares.

Regarding the second pillar - Regulation of UAV flights - it is important to note that although the majority of drone services are VLOS flights, the share of BVLOS flights is steadily increasing. From 2022, EASA has already granted Design Verification approval to several UAV manufacturers and operators, which enables the use of BVLOS flights. So far, UTM systems have been implemented in three countries in Europe: Poland, Norway and Switzerland. Procurement and development work is underway in many EU countries in connection with the EU U-space directives that will enter into force on 26.10.2023. The implementation of EU Regulation 947/2019 and the U-space regulation will contribute to the increased adoption of automated and BVLOS flights, where 5G mobile networks will play an important role. The roll-out of U-space additional services is planned for 2022-2026.

For the third pillar - Regulation of Radio Communication - it is important to note that as of today, most EU countries allow the addition of mobile communication devices on board UAVs and the use of 5G communication for controlling UAVs. However, in Finland, for example, it is limited, and you need to apply for permission from Traficom separately. On 17.11.2022, the ECC adopted Decision No. 22(07), which provides for the adoption of national regulations from 2023, which, if necessary, stipulates restrictions on the use of certain mobile communication frequencies for the control of UAVs. The purpose of the restrictions is to describe interference mitigation measures and locations based restrictions.

Concerning the fourth pillar – UAV models with 5G devices – it is important to note that since August 2021, Qualcomm in cooperation with ModalAI started offering a drone for sale with a 5G modem on board, which enables drone control over 5G. An important step in the development of the field was also the launch of the Mavic3 drone model controlled via 4G by the world's largest drone manufacturer DJI (which produces an estimated 70% of commercial drones in the world) from the end of 2021.

Considering the fifth pillar - 5G rollout - it is important to note that after the Covid-19 restrictions, auctions of 5G licenses for both 3.5GHz and 700MHz frequencies have been conducted in many EU countries. By 2025, it is planned to cover cities in most EU countries with 5G coverage. It is also expected that 5G MEC-based services will enter the market from 2025, which is important for the provision of services related to large volumes of data by drones.

Closing with the sixth pillar – Standardization – it is important to note that various technical and procedural aspects are covered in depth in the 3GPP Release 16, 17 and 18 working documents. The 3GPP standardization work is very important so that mobile operators and UAV operators operate on a uniform basis.

5 Conclusion

This deliverable, as an updated version of its previous release (D1.4), provides an analysis of the current state of the overall UAV market, the corresponding regulatory environment, with a particular focus on the role of 5G technology and how 5G!Drones trials and results can further influence the evolving UAVs market and business environments.

The updated EU regulatory framework (2020-2022 period), including UAV flights categories, regulations and 5G spectrum policies, and their impact to the prevailing use cases, was analysed, highlighting the importance of the need for clear and sound regulations, commonly applied to all European countries, for safer but also easier use of drones in various market and business sectors of EU societies.

The impact created in the UAVs market and business environment by the 5G!Drones use cases and the four 5G experimental platforms was presented by the 5G!Drones consortium, based on the experience and knowledge gained, and by making recommendations, providing insights and future pathways for the further evolution of the UAVs in the upcoming 5G business and market environments.

During the project's period, 5G!Drones partners were working together and sharing knowledge from different disciplines to ensure that 5G!Drones trials, their results and rest project achievements would lead to a novel UAV operation have framework within a niche business, market and regulatory environment, where 5G-UAV services will be available, new markets will be targeted, new business processes will be formed and new regulations will apply and guide UAV business and market related activities within the newly formed 5G environment.

This 5G!Drones vision has been successfully addressed in this deliverable where UAVs high market potential has been confirmed, niche regulatory framework is under serious consideration and application in Europe, 5G-UAVs coupling is proven feasible, leading to new markets, products and services, opening new innovative future pathways both for the scientific communities but also for the European societies, despite certain shortcomings (in legal, technological, societal areas) that are spotted and will be overcome in the near future.

6 ANNEX

6.1 Operational Safety Objectives (OSO)

The last step of the SORA process is to use the SAIL to evaluate the defences within the operation in the form of OSOs, and to determine the associated level of robustness. Table below provides further details on the OSO identification In specific, it provides a qualitative methodology to make this determination. In this table, O is optional, L is recommended with low robustness, M is recommended with medium robustness, and H is recommended with high robustness. The various OSOs are grouped based on the threat they help to mitigate; hence, some OSOs may be repeated in the table.

Table 10 Indicative OSOs identification[185]

OSO Number		SAIL					
	Technical issue with the UAS	I	II	III	IV	V	VI
OSO#1	Ensure the UAS operator is competent and/or proven	O	L	M	H	H	H
OSO#2	UAS manufactured by competent and/or proven entity	O	O	L	M	H	H
OSO#3	UAS maintained by competent and/or proven entity	L	L	M	M	H	H
OSO#4	UAS developed to authority recognised design standards	O	O	L	L	M	H
OSO#5	UAS is designed considering system safety and reliability	O	O	L	M	H	H
OSO#6	C3 link performance is appropriate for the operation	O	L	L	M	H	H
OSO#7	Inspection of the UAS (product inspection) to ensure consistency with the ConOps	L	L	M	M	H	H
OSO#8	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#9	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO#10	Safe recovery from a technical issue	L	L	M	M	H	H
	Deterioration of external systems supporting UAS operations						
OSO#11	Procedures are in-place to handle the deterioration of external systems supporting UAS operations	L	M	H	H	H	H

[185] https://eudronebewijs.nl/blogs/actueel/zo-voer-je-een-sora-uit-deel-5-van-5

OSO#12	The UAS is designed to manage the deterioration of external systems supporting UAS operations	L	L	M	M	H	H
OSO#13	External services supporting UAS operations are adequate for the operation	L	L	M	H	H	H
	Human error						
OSO#14	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#15	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO#16	Multi-crew coordination	L	L	M	M	H	H
OSO#17	Remote crew is fit to operate	L	L	M	M	H	H
OSO#18	Automatic protection of the flight envelope from human error	O	O	L	M	H	H
OSO#19	Safe recovery from human error	O	O	L	M	M	H
OSO#20	A human factors evaluation has been performed and the human machine interface (HMI) found appropriate for the mission	O	L	L	M	M	H
	Adverse operating conditions						
OSO#21	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#22	The remote crew is trained to identify critical environmental conditions and to avoid them	L	L	M	M	M	H
OSO#23	Environmental conditions for safe operations are defined, measurable and adhered to	L	L	M	M	H	H
OSO#24	UAS is designed and qualified for adverse environmental conditions	O	O	M	H	H	H