6G for Connected Sky
"6G-SKY"

Work Package 1:

Holistic Adaptive Combined Airspace and NTN networks Architecture for 6G

Deliverable D1.1:

Combined Airspace and NTN networks use cases, scenarios and regulations

6G-SKY Project :

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Abstract

D1.1 Combined Airspace and NTN networks use cases, scenarios and regulations intents to provide an overall framework of descriptions and analysis for combined Airspace and NTN networks including definition of holistic aerial networks, identification and analysis of international programs for Innovating the Digital European Airspace and beyond, 6G regulations and spectrum for combined Airspace and NTN networks (combined ASN networks), 6G use case segments for digital airspace and NTN, Highlighted 6G-SKY use cases, 6G-SKY demo use cases, and combined ASN networks impact on sustainability.

Participants in WP 1:

6G-SKY, Work Package 1: Holistic Adaptive Combined Airspace and NTN networks Architecture for 6G

Task 1.1: Use cases, scenarios and regulations

- Sub-Task 1.1.1: Use cases and scenarios
- Sub-Task 1.1.2: Spectrum and Airspace Regulations

D1.1 Combined Airspace and NTN networks use cases, scenarios and regulations

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6G-SKY: D1.1 Combined ASN networks use cases, scenarios and regulations

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Executive Summary

This deliverable is intended for those readers that have an interest to get an overall view and understanding of combined Airspace and NTN networks (combined ASN networks).

The main benefits are that the D1.1 Combined Airspace and NTN use cases, scenarios and regulations provide an overall framework of descriptions and analysis for combined ASN networks including a definition of holistic aerial networks, an identification and analysis of international programs for Innovating the Digital European Airspace and beyond, 6G regulations and spectrum for combined ASN networks, 6G use case segments for digital airspace and NTN, highlighted 6G-SKY use cases, 6G-SKY demo use cases, and a combined ASN networks impact on sustainability. This material can be further used to trigger research investigations and commercial actions for the readers of the deliverable.

Some of the most important findings are:

- The definition of holistic aerial networks has been analyzed.
- The terminology for holistic aerial networks is proposed to be combined Airspace and NTN networks, abbreviated combined ASN networks.
- The following use case segments have been identified for combined ASN networks: commercial airplane traffic, connectivity for rural and remote areas, satellite connectivity to terrestrial networks for non 3GPP services, urban air mobility, verticals beyond UAM, IoT and combined ASN networks and NTN integration towards ATM, UTM, societal management systems and national security systems.
- An air taxi use case has been used to identify regulatory and spectrum challenges for aerial platforms on low altitude levels in Sweden. The use case shows the importance of having a holistic approach as aerial platforms will interact with each other. The approach and findings can be applied towards other markets, even if regulations are different between markets and that the findings need to be adapted.
- Regulatory aspects are still considered to be in its infancy for low altitude platforms and will evolve.
- ATM will be complemented with UTM to handle the massive growth of aerial platforms. This will drive automization and digitalization of airspace and NTN.
- Aviation will move from a human centric system towards an information centric system.
- The EU commission underscores that U-space service providers should be able to capitalize on the existing mobile telecommunication technologies and standards.
- EU is heading for a digital European sky by 2040, supported by the ESA and SESAR initiatives.
- 6G-SKY is aligned with SESAR having a holistic approach to aerial platforms to fully benefit from aligning digital efforts towards aerial platforms.
- There is an opportunity that Europe will take a lead in the digitalization of aerial platforms and with supportive systems around, including fueling a digital ecosystem
- The regulatory issues identified by 6G-SKY that impose challenges are: institutional structure and competent authorities, technology development, spectrum management, cyber security and related national aspects, and future market, competition and business models.
- Sustainability will play a key role for the evolution of airspace and NTN networks supported by electrification and use of non-fossil propulsion mechanisms, as well as digital solutions supported by 6G.

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Glossary

List of acronyms with alphabetical order.

Acronym	Description
A2G	Air to Ground
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
ANSP	Air Navigation Service Provider
ASN	Airspace and NTN
ATC	Air Traffic Control
ATM	Air Traffic Management
BSS	Broadcasting-satellite service
BVLOS	Beyond visual line-of-sight
CEPT	European Conference of Postal and Telecommunications Administrations
CIS	Common Information Service
CNS	Communication, Navigation and Surveillance
Combined ASN networks	Combined Airspace & NTN networks
DME	Distance measuring equipment
EASA	European Union Aviation Safety Agency
ECO	European Communications Office

eVTOL	Electrical Vertical Take-Off and Landing
FAI	Fédération Aéronautique Internationale
FBW	Fly-by-wire
FCC	Federal Communications Commission
FCS	Flight Control System
FSS	Fixed-satellite service
FW	Fixed Wing
GEO	Geostationary Orbit
HIBS	High Altitude IMT Base Stations (HIBS)
HAO	Higher Airspace Operations
HAPS	High Altitude Platform Station
IAM	Innovative Air Mobility
IATA	International Air Transportation Association
ICAO	International Civil Aviation Organization
ICNS	Integrated Communication, Navigation and Surveillance
ITU	International Telecommunication Union
IMT	International Mobile Telecommunications
IoT	Internet of Things
LAPS	Low Altitude Platform System
LEO	Low Earth Orbit
LOS	Line of sight
MBB	Mobile Broadband
MEO	Medium Earth Orbit
MSS	Mobile-satellite service
NGSO	Non-Geostationary Orbit
NOC	Network operation centre
NRA	National regulatory authorities
NTN	Non Terrestrial Networks
RPAS	Remotely Piloted Aircraft System
SATCOM	Satellite Communication Systems
SES	Single European Sky
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research

Smart city	A smart city is an "innovative city that uses information communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects"
SORA	Specific operations risk analysis
STM	Space Traffic Management
TN	Terrestrial Networks
UAM	Urban air mobility
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UTM	Unmanned Traffic Management
VOR	Very high frequency omnirange station
WET	Wireless energy transfer
WRC	World Radio Conferences
3GPP	3rd Generation Partnership Project

1. Introduction

The 6G-SKY project addresses emerging communication technologies that have strategic importance in Europe and impact on the innovation of new technologies for wireless communication and computation in the sky. The 6G-SKY project provides connectivity services for different types of users both in the sky or on the ground, such as Urban Air Mobility (UAM), commercial airplanes, and Internet of Things (IoTs). The 6G-SKY project targets to strengthen Europe's position in these strategic areas and also offer new business opportunities for European companies.

1.1 Objective of the document

The D1.1 Combined Airspace and NTN networks use cases, scenarios and regulations has two main purposes:

- It provides inputs for other work packages within 6G-SKY.
- It provides a deliverable open for external use.

The deliverable intents to discuss definitions of networks for aerial platforms, provide regulatory and spectrum insights, provide an overall segmentation for aerial platforms on all altitude levels, provide analysis from different perspectives on use case segments, and describe use cases derived from WP1 tasks as well as providing demo use case scenarios.

1.2 Structure of the document

D1.1 is structured accordingly: chapter 2 provides an overview of innovating the digital European airspace and beyond, including EU initiatives SES and SESAR; chapter 3 provides a description and analysis of spectrum and regulations; chapter 4 describes 6G use case segments for digital airspace and NTN; chapter 5 provides a use case segment analysis; chapter 6 introduces descriptions of aerial platforms; chapter 7 provides a set of highlighted use cases used in the 6G-SKY project in different WP1 tasks; chapter 8 provides an introduction to the demo scenarios that will be covered in 6G-SKY WP5; chapter 9 will provide and analysis of combined ASN and NTN networks impact on sustainability; and finally, chapter 10 will provide conclusions.

1.3 Definition of Holistic networks for aerial platforms

The definition of holistic networks for aerial platforms is influenced by several factors and can differ in different contexts. 6G-SKY has evaluated naming terminologies for holistic networks covering all aerial platforms at all altitude levels. The main evaluated naming terminologies have been:

- NTN in its wider sense
- Airspace
- Aerospace
- Combined Airspace and NTN networks

Each naming terminology has been analyzed from the adherence to the following viewpoints: adherence to SESAR terminologies, 3GPP terminologies, spectrum terminologies, university terminologies, and general acceptance of the proposed terminology. In conclusion, 6G-SKY has chosen the following naming terminology for holistic networks covering all aerial platforms at all altitude levels: Combined airspace and NTN networks, abbreviated combined ASN networks. Combined ASN networks are integrated with the terrestrial networks.

The chosen naming terminology is considered to have the greatest chance to win acceptance among different stake holders. For combined ASN networks, airspace is considered to encompass all aerial platforms that can fly, including HAPS/HIBS. NTN is considered to be space based aerial platforms, such as satellites.

1.3.1 NTN in its wider sense

NTN in its wider sense was introduced by 1], see figure below:

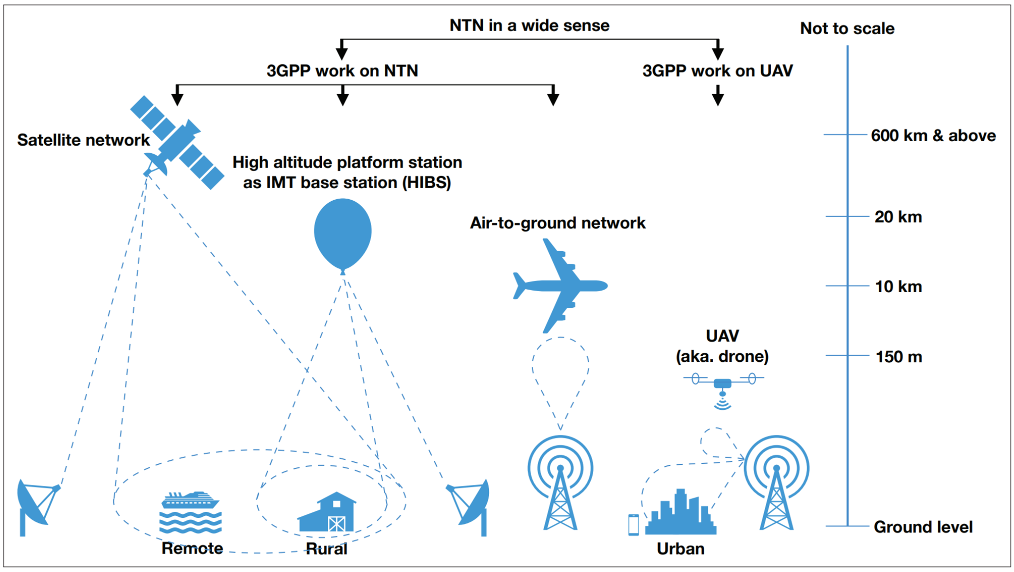

Figure 1: Different types of non-terrestrial networks.

The attempt here has been to take a word, NTN, that for many is associated with satellites, and broaden its meaning to cover all aerial platforms at all altitude levels. It is very hard to get an acceptance for this widening and it may also create confusion among stakeholders. In many cases, there is a need to define NTN at every occasion whether it is viewed as a term for satellites or used in its wider sense. When 6G-SKY was established NTN was viewed in its wider sense. 6G-SKY has now chosen to refer NTN to satellites. This resonates well with 3GPP that uses NTN for satellites in TS 38.300.

1.3.2 Airspace

Airspace is a term that is used widely within SESAR [REF _Ref116634164 \n \h2]. The issue with Airspace is that it may exclude satellites [3], see below:

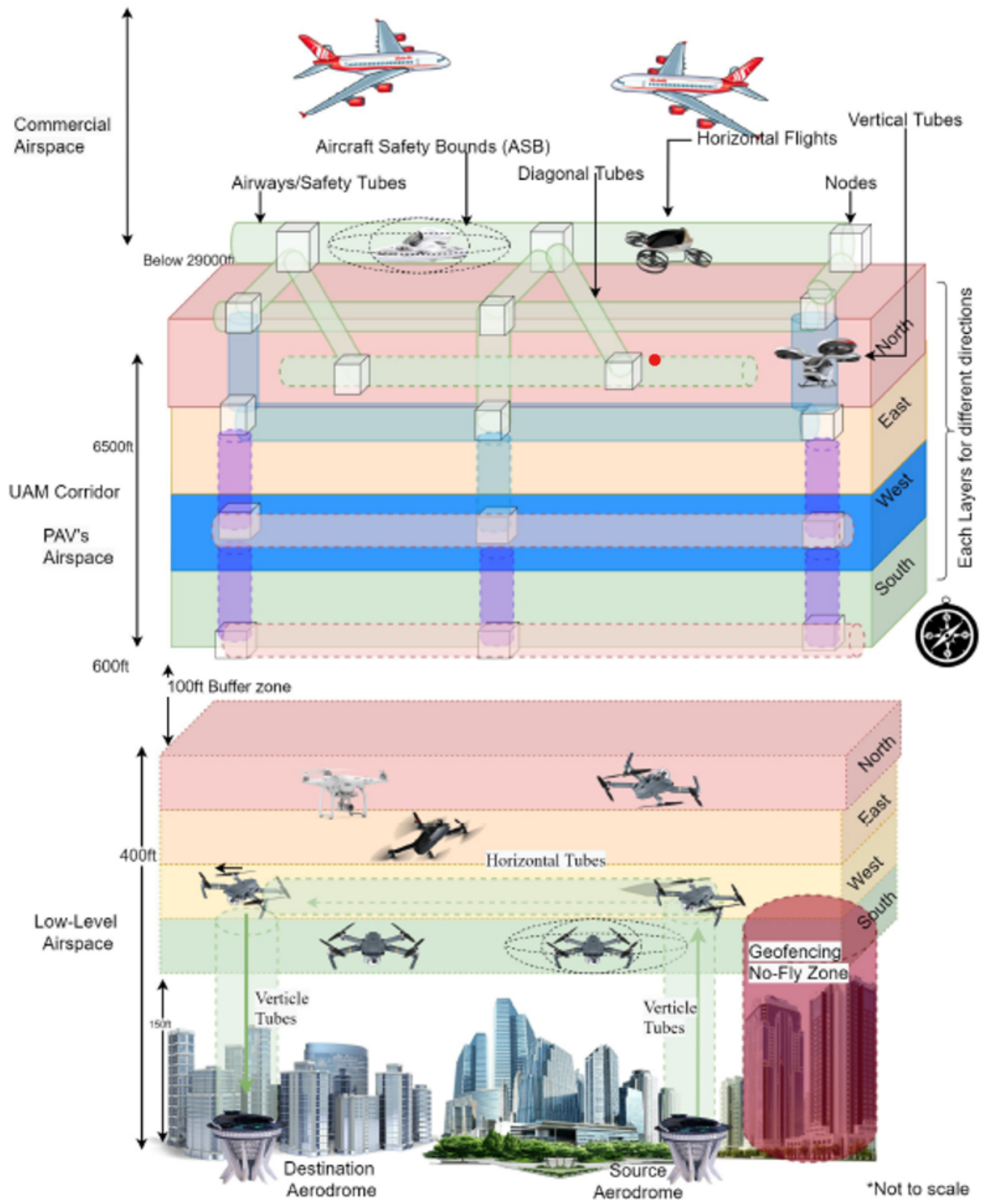

Figure 2: Airspace networks

1.3.3 Ground Air Space networks

Ground Air Space networks was introduced by [4], see figure below:

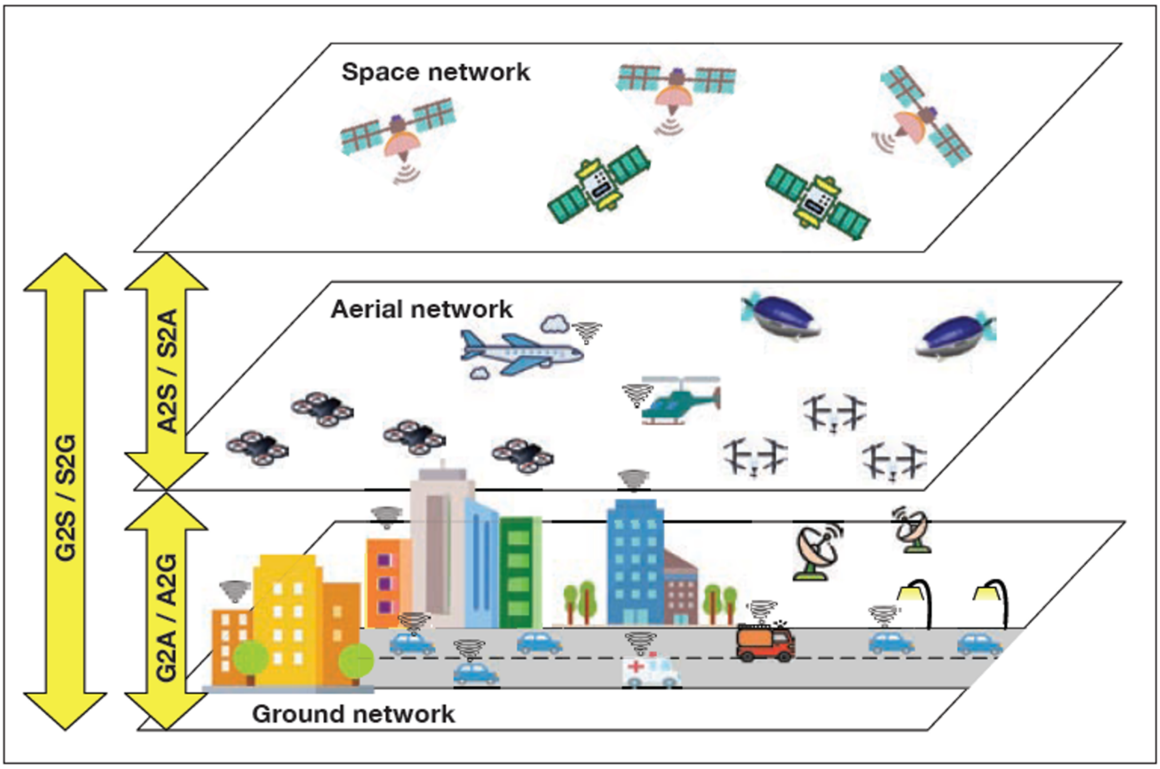

Figure 3: Ground Air Space networks

This model creates some confusion with the terms e.g., used within 3GPP, where ground networks are referred to as terrestrial networks.

1.3.4 ITU regulations

ITU has defined two types of radio communication:

- Terrestrial radio communication: any radio communication other than space radio communication or radio astronomy.
- Space radio communication: any radio communication that involves the use of one or more space stations, the use of one or more reflecting satellites, or of other objects in space.

The ITU definitions are most likely not easy to transform. Also, the definitions are limitedly used by other stakeholders e.g. SESAR. The naming terminology proposed by 6G-SKY does not contradict the ITU regulations and it is valid to state that both terminologies can co-exist.

1.3.5 Conclusion

The Combined ASN networks naming has some disadvantages. It would perhaps have been more practical to have a single name for holistic networks. But whichever name that is introduced must also be viewed from the perspective that it can get general acceptance among stakeholders. Combined ASN networks works well for most stakeholders. It resonates well with the usage of Airspace in SESAR, NTN in 3GPP and also works for academic research papers that many times use the terms Airspace and NTN.

2 Innovating the Digital European Airspace and beyond

Airspace innovation is ongoing worldwide. The development and expected growth of various new aerial platforms, along with adopting the society towards a sustainable digital environment with focus on automation and electrification of vehicles and aircrafts, fuel innovation for airspace. Manufacturer of UAVs and drones and the emergence of new aerial platforms actors are all contributing to this airspace innovation. Another significant factor that is contributing to airspace innovation is the substantially reduced costs of space launches and the development of reusable rockets used for these space launches.

An increase of space launches provides greatly expanded opportunities to exploit space for commercial users. Competition amongst satellite actors drives innovation, forces efficiency and overall reduces costs. Traditionally, access to space has been extremely expensive. However, with falling prices and as new technologies are developed such as the potential of reusable rockets, the sector has become more commercialized.

Various initiatives are pushing towards airspace innovation. In the US, the Next Generation Air Transportation System (NextGen) [1] is the FAA's program to modernize the national airspace system. Europe has also very bold plans to create a Digital European Airspace by 2040. The European Union Aviation Safety Agency, the Federal Aviation Administration, and aviation actors Airbus and Boeing are working together to propose a common vision for the future aviation connectivity with a time horizon 2030-2035, which greatly matches the 6G timeline [5].

2.1 SESAR and SES

Since the Chicago Convention in 1944, the regulatory framework in aviation has primarily been shaped on an international basis through the UN agency International Civil Aviation Organization (ICAO) [2]. EU has since the introduction of the Single European Sky in 2004 been the regulatory authority and the Swedish Transport Agency is completely subordinate to the EU regulatory authority EASA [3].

The air traffic service is to a large degree still dependent on old-fashioned communication solutions, i.e. in the form of VHF radio which is the main communication mode between pilot and air traffic controller, although simpler data link solutions are also used. In order to modernize Air Traffic Management within Europe the Commission launched the first SESAR (Single European Sky ATM Research) project in 2004 and development work has been ongoing since then [6].

The current project is SESAR 3 joint undertaking, which aims to modernize Europe's air and ground ATM infrastructure and operational procedures. Thus contributing to a smarter, more sustainable, better connected and accessible air transport system. EU has the intention to create the Digital European Airspace by 2040. The background is an analysis of that aerial platforms will grow in types and use. The growth of aerial platforms will require automation of the airspace, which in turn will drive digitalization of the European airspace. The vision is described in the European ATM master plan as follows [5:

"By 2040, increasing numbers of aerial vehicles (conventional aircraft and unmanned aircraft, such as drones) will be taking to Europe's skies, operating seamlessly and safely in all environments and classes of airspace. Trajectory based free-route operations will enable airspace users (civil and military) to better plan and execute their business and mission trajectories within an optimised airspace configuration that meets safety, security and environmental performance targets and stakeholder needs. The system

infrastructure will progressively evolve with the adoption of advanced digital technologies, allowing civil and military ANSPs and the Network Manager to provide their services in a cost-efficient and effective way irrespective of national borders, supported by secure information services. Airports and other operational sites (e.g. landing sites for rotorcraft and drones) will be fully integrated at the network level, which will facilitate and optimise airspace user operations in all weather conditions. ATM will progressively evolve into a data ecosystem supported by a service-oriented architecture enabling the virtual defragmentation of European skies. Innovative technologies and operational concepts will support a reduction in fuel and emissions while also mitigating noise impact, in support of the EU's policy of transforming aviation into a climate-neutral industry. Performance based operations will be fully implemented across Europe, allowing service providers to collaborate and operate as if they were one organization with both airspace and service provision optimised according to traffic patterns. Mobility as a service will take intermodality to the next level, connecting many modes of transport, for people and goods, in seamless door-to-door services".

The EU aviation strategy [7] acknowledges SES and SESAR [6] as key drivers of sustainable growth and innovation in air transport:

- The Single European Sky (SES) is an ambitious initiative launched by the European Commission in 2004 to reform the architecture of European ATM. It proposes a legislative approach to meet future capacity and safety needs at a European rather than local level.
- Single European Sky ATM Research (SESAR) is a EU research program to drive the evolution towards a digital European sky by 2040

SESAR proposes a holistic target architecture and suggests a four phased approach for improvements:

A. Address known critical network performance deficiencies.
B. Efficient services and infrastructure delivery.
C. Defragmentation of European skies through virtualization.
D. Digital European sky.

SESAR proposes a tightly integrated architecture, which means that the infrastructure must support all layers and functions of the target architecture:

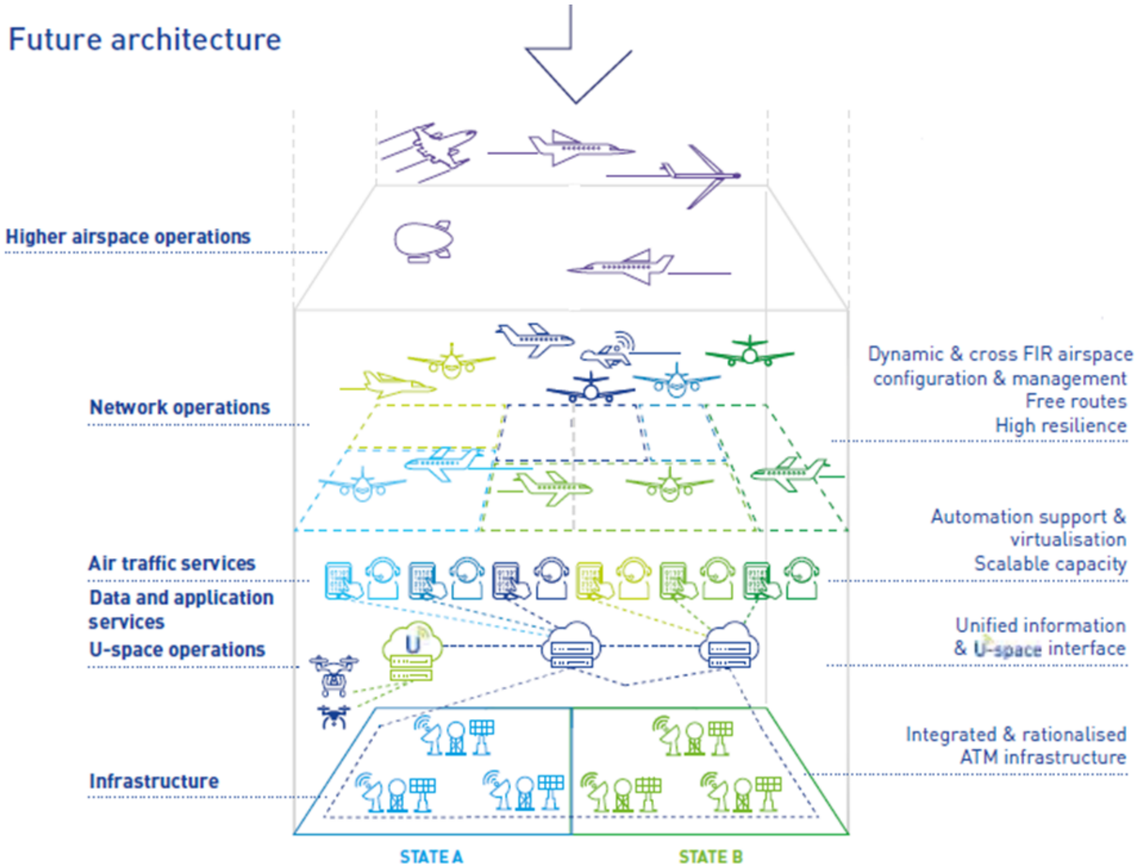

Figure 4: SESAR Target architecture.

2.2 6G-SKY relation towards SESAR

The four phased approach towards Digital European Airspace, proposed by SESAR, is timed towards 2040. For 6G-SKY, phases C - Defragmentation of European skies through virtualization, and D - Digital European sky are of extra interest.

SESAR has also defined a roadmap for U-space. U-space can be seen as an enabling framework for the development and deployment of a fully automated and scalable drone management system [6]. U-space consists of a set of services that completely relies on digitalization and automation of functions and procedures designed to support safe, efficient, and secure access to airspace for large numbers of drones.

U-space relies on a high level of autonomy and connectivity in combination of new and innovative technologies designed to facilitate any kind of routine mission in all types of airspace environments, even the most complex and congested ones, while staying connected with manned aviation and air traffic control.

In support of this initiative, in 2017 the SESAR Joint Undertaking drafted the U-space blueprint, which is a vision of how to make U-space operationally possible. The deployment of U-space is envisaged in an incremental manner and will be implemented in four phases, moving from U1 (U-space foundation services) to U2 (U-space initial services), U3 (U-space advanced services), and U4 (U-space full services).

The U-space blueprint proposes the implementation within the designated time of 2019 to 2040, as shown in Figure 5 below, to support the EU aviation strategy and regulatory framework on drones. Each new phase will introduce a new set of services while including an upgraded version of the services already existing in the previous phase. 6G-SKY will mainly address U3 and U4.

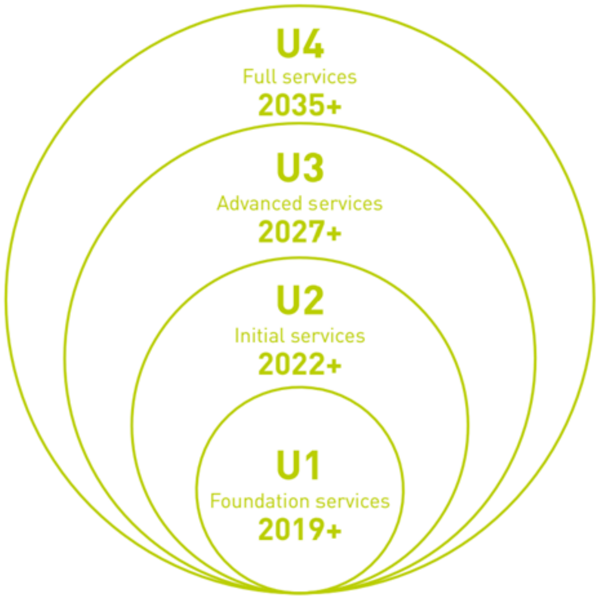

Figure 5: U-Space roadmap according to European ATM master plan [5

- U1 – foundation services: will consist of services with the main objectives to identify drones and operators and to inform operators about restricted areas.
- U2 – initial services: will consists of a set of initial services designed to support the safe management of BVLOS operations. Will also include services for drone operations management, including flight planning, flight approval, tracking, and interfacing with conventional air traffic control.
- U3 – advanced services: will build on the experiences gained in U2 and will unlock new and enhanced applications in high-density and high-complexity areas supporting more complex operations in dense areas such as assistance for conflict detection and automated detect and avoid functionality. This is where the most significant growth in drone operations is expected to occur, especially in urban areas, with the initiation of new types of operations, such as air urban mobility.
- U4 – Full service: will offer very high levels of automation, connectivity and digitalization for both the drones and the U-space system.

The future airborne transport systems with urban air mobility (UAM) with flying vehicles, like flying taxis, unmanned vehicles and other flying object require a digitalization of the sky in order to provide automation of air management systems, which require appropriate access to spectrum. This development could contribute to a more social and healthier environment in cities.

Drones are a growing business in Europe, delivering services in all environments, including the urban areas. Mapping, infrastructure inspections, precision agriculture, delivery of goods and e-commerce are just some of the services possible using drones.

Drone operators and U-space service providers need to comply with regulations set by the European Union Aviation Safety Agency (EASA). The European regulatory framework and the first U-space regulations, adopted by the European Commission will come into force in January 2023. A clear framework at EU level would allow the creation of a truly European market for drone services and aircraft, thereby harnessing potential for jobs and growth creation in this new sector of the economy.

2.3 Advanced Air Mobility

Advanced Air Mobility (AAM) is a vision driven by NASA to materialize an air transportation system to enable mobility of people and cargo mobility in areas where the current aviation cannot serve [4]. AAM covers local, regional, inter-regional and urban areas through new aircraft such as electric Vertical Take-Off and Landing (eVTOL) and UAVs. This vision aims to support the aviation market and provide benefits to the public. This vision is started by the Aeronautics Research Mission Directorate (ARMD) to elevate cooperation among different players such as industry and state government and other government agencies such as FAA via ARMD projects.

AAM ecosystem is being realized through working groups (WGs) consisting of different elements such as aircraft, airspace, community integration, and crosscutting. Aircraft WG focuses on aircraft design, operations management, flight automation, and manufacturing. Airspace WG deals with the design of airspace, flight procedures, UTM UAS services, and operations.

Community Integration WG consists of government bodies (federal, state, and local municipalities), community and industry-based groups and operators. Crosscutting WG includes standards and requirements for the concept of operations and national campaign [4].

These WGs contribute to the Organizational Framework, which is divided into five main pillars. These pillars can be listed as follows [4]:

1. Vehicle development and production - design, manufacture, and system readiness of AAM vehicles.
2. Individual vehicle management and operations - operations and maintenance of AAM vehicles, sharing of the airspace.
3. Airspace system design and implementation - design, development and implementation of infrastructure.
4. Airspace and fleet operations management - multiple vehicles in AAM sharing the airspace.
5. Community integration - societal integration and acceptance of AAM operations.

3 Spectrum and Regulations

Chapter 3 addresses a broad range of issues related to spectrum and regulation covering electronic communication, aviation and space.

Chapter 3 will start with looking at regulatory frameworks, then describe an air taxi use case, then derive consequences based on the described use case, following with a state of the art analysis of spectrum and finally an analysis of regulatory challenges based on the use case and general findings.

3.1 Framework

3.1.1 Framework regarding airspace

A future user group of multilayer networks, which combines airspace and Non-Terrestrial Networks (NTNs) with terrestrial networks are eVTOLs (electric vertical take-off and landing) like flying taxis. This is an example of Advanced Air Mobility, which according to NASA, is a safe, accessible, automated, and affordable air transportation system for passengers and cargo capable of serving urban and rural locations [8]. This could potentially decrease air pollution and congestion in various ground transport sectors contributing to the green and digital transition.

The expected increase in the airspace traffic with manned and unmanned vehicles, such as drones has a great economic potential. It should be noted that electric propulsion in general may impact a wide range of future aeronautical applications with different time horizons, i.e. traditional manned airplanes for passengers and goods, manned helicopters as well as a variety of unmanned aircrafts initially on a lower altitude (below ~150 m).

In November 2022, the European Commission presented its Drone Strategy 2.0 for a smart and sustainable ecosystem for unmanned aircraft in Europe. The Commission states that with the right framework in place, the market for drone usage in Europe could be worth EUR 14.5 billion and create 145,000 jobs until 2030 [9]. If European countries want to be part of this development and create more jobs nationally or in the single market, investments need to be made for adapted and coordinated regulation and develop drone supporting infrastructure.

In short, the aim for 6G-SKY is to identify different connectivity solutions specific to certain limited domains, integrated connectivity solutions and design a holistic network architecture, which is vital to unlock the potential of the recent technology advances and create new innovative applications. However, depending on the range of altitude different challenges will most likely arise. Below 150 meters the most readily available integration with terrestrial mobile systems can be seen.

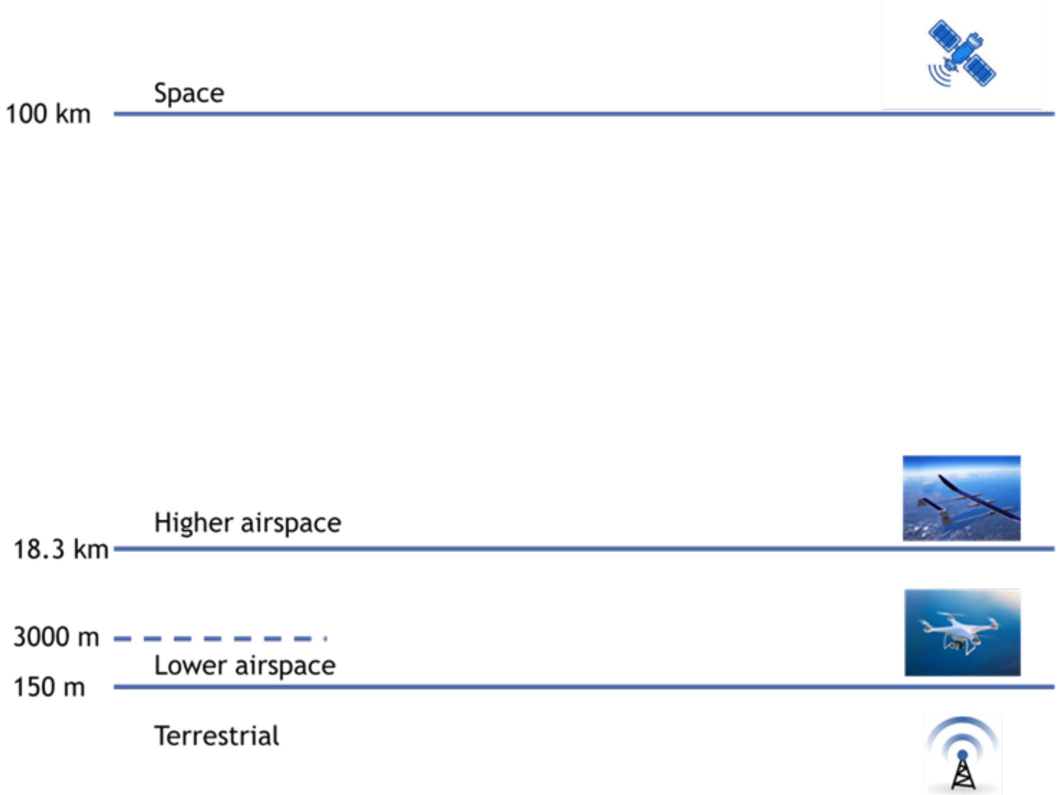

Figure 79: The altitudes from terrestrial, airspace to space. Source: PTS, Sweden.

In addition, the U-space environment can be expected to be developed step by step with geographical expansion over time. 3000 m may also have a role to play in this context since traditional aeronautical use below this altitude primarily consists of climb to or descent from cruising altitude. Furthermore, the minimum height above ground for any transmission from a system in operation must be 3000 m for mobile communications services on air crafts according to the amendments by the Commission implementing decision (EU) 2022/2324.

Essentially, regulation of civil aviation concerns the airspace up to 18300 m, which will serve as the boundary to higher airspace. Finally, based on a definition that space starts at 100 km, above which altitude the satellites operate, leaves a higher airspace up to such altitude for new types of future aerial platforms.

Let alone technical challenges developing holistic aerial networks as well as flying vehicles, such as eVTOLs, raise a number of regulatory challenges that are of relevance for the wider aviation sector. In order to highlight these challenges this chapter presents a use case with a family traveling with a flying taxi from Stockholm to Uppsala, the fourth largest city in Sweden situated 70 km north of Stockholm.

Given that it is a fictitious journey we have taken some liberties by looking beyond current helicopter solutions and stretched the application in order to attract attention to possible restrictions as the aim with the use case is to highlight regulatory challenges with the development of 3D communication solutions for the aviation sector as well as other user groups. Although recognizing the significance of the potential for the development of unmanned aircrafts that will primarily operate in the airspace up to 150 m where the dedicated U-space will be located, this case takes a long-term view.

For the foreseeable future, eVTOLs carrying passengers will be piloted. From a regulatory standpoint they are similar to helicopters, but specific regulations for eVTOLs are being introduced. Moreover, the aviation sector works with a long-term perspective, which means that introduction of hyperconnected ATMs [10] will not be a reality in the near future.

The concept hyperconnected ATM is used in [10] which is a project that explores the integration of non-safety communication infrastructure for ATM safety communication needs. It is a forward looking concept as the hyperconnected ATM technology assumes that it will become acceptable and beneficial to use public non-safety commercial communication systems as a component of aircraft safety communication [10]. This makes the concept relevant for a future looking use case as it is outlined in the following section.

The airspace and the aeronautical sector is subject to extensive regulation in order to guarantee safe, efficient and environmentally sound air traffic. Since the Chicago Convention in 1944, the regulatory framework in aviation has primarily been shaped on an international basis through the UN agency International Civil Aviation Organization (ICAO). EU has since the introduction of the Single European Sky in 2004 been the regulatory authority, where national regulatory agencies, like the Swedish Transport Agency is completely subordinate to EASA.

A number of things need to happen and the regulation of the airspace has to undergo a fundamental shift in order to facilitate the take-off for the eVTOL from the vertiport in central Stockholm that will be described in the following paragraph. It should be permitted to fly eVTOLs in central Stockholm and Uppsala, which require that current restrictions imposed by the Swedish Transport Agency, the armed forces and the Swedish security services are overtaken [11].

This would have a fundamental effect on the management of the aerial traffic, which has to be addressed in order to guarantee safe and reliable air traffic. Moreover, there are a number of other issues that need to be addressed in order to make the use case feasible. These issues are presented in the next section followed by a policy discussion.

3.1.2 Regulations regarding unmanned aircraft systems

In order to manage the increasing number of unmanned aircraft systems (UAS), also considering the overlap of manned and unmanned airspace users in certain situations and its safe integration, the concept of U-space has been established [12]. By using different technological and communication-related services, exchange of information regarding airspace participants is provided, which includes the involvement and coordination of aviation authorities, air navigation service providers (ANSPs), and U-space service providers (USSPs) [12].

The EASA recently (by 16 December 2022) published a U-space related regulatory package, the AMC and GM to Implementing Regulation (EU) 2021/664 — Issue 1 [5], which details U-space-related questions. From a technological point of view and depending on the requirements, different features can be implemented while designing a U-space architecture. A main component of U-space is service enabling traffic management, which is referred to as unmanned traffic management (UTM). Another core component of U-space is common information service (CIS).

UTM is a system that enables the safe, economical and efficient integration of UAS, into the airspace alongside manned aircraft. The integration of UAS is a joint undertaking and requires large-scale demonstration, which received funding by the European Union in the project "GOF 2.0 Integrated

Urban Airspace Validation". A main outcome of this project is the specifications of a range of relevant services [13].

A UTM system manages the flow of drone traffic in a similar way to air traffic control for manned aircraft, with the primary goal of ensuring the safety and efficiency of the airspace [14]. The UTM system consists of a range of technologies, procedures, and protocols that enable communication, coordination, and collaboration between drone operators, air traffic control, and other airspace users. The related technologies comprise, e.g., automatic dependent surveillance-broadcast (ADS-B), satellite-based navigation, and communications systems to track and communicate with drones in real-time.

CIS (Common Information Services) is a key component of U-space architecture in Europe. It aims at ensuring information exchange between UAS operators, ANSPs, and other relevant stakeholders. CIS enables real-time communication and collaboration among different actors in the U-space. CIS comprises a wide range of services such as flight planning and airspace management. It also provides access to real-time weather and environmental data, as well as information regarding temporary flight restrictions and other airspace constraints. In addition, the CIS enables remote identification and tracking of UAS.

A key component of the CIS is its open architecture, which facilitates interoperability between other U-space components and third-party systems. When it comes to implementing U-space services, interoperability between different services, service providers, and involved parties need to be established [15]. This also ensures that CIS can adapt to evolving needs and requirements.

Provided that these aforementioned services are implemented, another precondition for a wide application of UAS is that flight operations in many cases need to be conducted beyond visual line of sight (BVLOS), e.g., in logistics [16,12]. The use of UAS will concentrate on the 'very low level (VLL) airspace', which is understood as the airspace below the airspace usually used by manned air traffic [17]. Even though air traffic in the VLL airspace will be primarily based on unmanned aircraft, manned flight operations will still need to take place in certain cases, e.g., for emergencies [12,18], which exemplifies why integrated approaches are needed.

3.2 Use case with a flying taxi

This use case will highlight selected communication scenarios for air taxis and drones. In deliverable D1.2 "First draft of combined ASN architectures for low altitude platforms for UAM and rural areas" a full set of communication cases are described for drones, air taxis and aircrafts. The use case is based on Swedish and European regulatory frameworks supporting a use case involving air taxis flying between two Swedish cities: Stockholm and Uppsala. Even though the use case has a Swedish context the issues and problems identified may be similar for many other countries and regions. Below, the use case is described.

3.2.1 Preparing for the take-off from Stockholm

The vertiport is located in the central part of Stockholm, on the rooftop of the city terminal, to which it is mandatory to pass a security check that requires a valid booking for a journey with an air taxi. The Airwish eVTOL has been assessed by EASA that concluded that the eVTOL model fulfills the special conditions for airworthiness requirements to mitigate risks associated with battery systems for eVTOLS and it has received the required certification [19].

This specific vehicle operated by Space City has recently been subject to an inspection, which turned out positive as EASA and the Swedish Transport Agency approved the vehicle with no objections. The pilot has the required credentials and certification, similar to what is required for helicopters, and thereby complies with the regulation issued by EASA.
The pilot is preparing for the flight by doing the mandatory security checks and testing software and communication links to make sure that they are functioning properly, and that the links including end points are secure.

The aircraft has been recharged and the battery meter indicate that it has a 100 percent capacity, which is sufficient to fly the air taxi to Uppsala, with an estimated distance of 70 km. Given the current weather conditions and assuming an average speed of 170 km/h the pilot estimate that that the journey will take around 25 minutes.

Space City is registered at the Swedish Transport Agency and has a license to carry out commercial transportation of passengers. The pilot has submitted a flight plan to the Air Traffic Control systems in line with the EASA regulation. The flight plan represents a fixed route for Space City which together with the Swedish Transport Agency has established a corridor between Stockholm and Uppsala passing Arlanda airport with certain restrictions to be met.

Space City has carried out a specific operations risk analysis (SORA) for the flight, utilizing dynamic connectivity and ground risk data, which have been submitted to EASA as well as to the Swedish Transport Agency.

3.2.2 The take-off

The passengers, a family consisting of five people, have checked in at the vertiport at the city terminal in Stockholm, and received green light to enter the air taxi as the pilot has completed all the checks. A ground crew assists the family in boarding the air taxi and instruct them to put the seat belts on. The air taxi is ready for take-off, the flight panel shows a green light, the electrical engines are on. The sight is clear, and the weather conditions are excellent for the journey. The family is very excited. They are comfortable and feel relaxed as they perceive that security and safety issues are handled in a professional way.

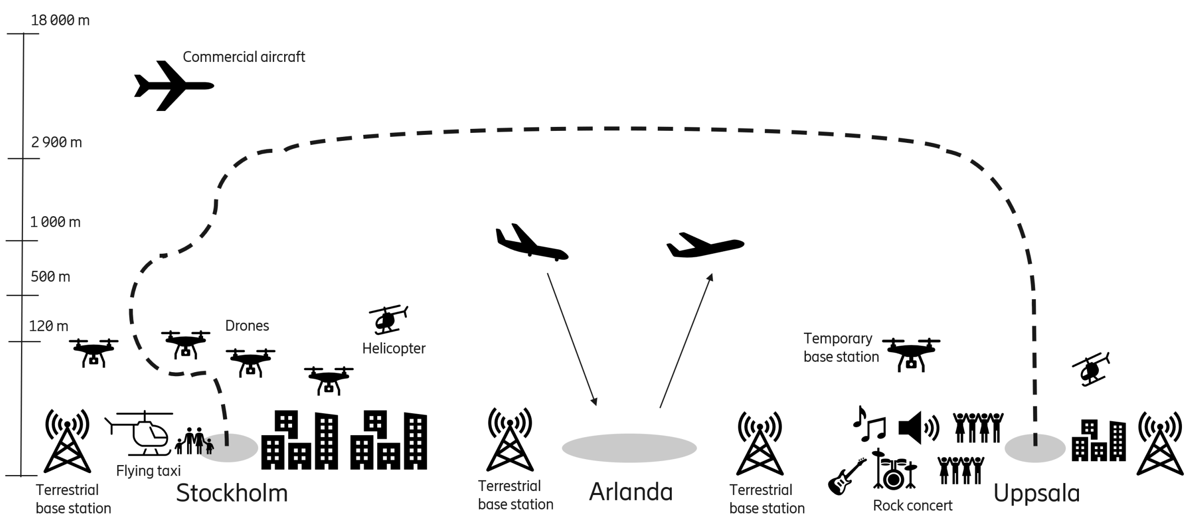

Figure 7: A family trip with an eVTOL

3.2.3 The climb

The first phase of the ascent goes up to 150 m, which is the limit for the open category for drones, requiring that the situational awareness display presented on the flight deck of the eVTOL has to show the traffic in the airspace.

How to handle interaction with other flying vehicles, drones, air taxis? The U-space defined airspace has come into place which is a UAS geographical zone designated by the regulatory authority. Depending upon drone category UAS operations are in most cases only allowed to take place with the support of U-space services [20].

U-spaces provide safe and coordinated joint airspace for the operation of both manned and unmanned aircraft. This is available through an app- and web-based service to monitor the activity in the lower airspace, up to 3000 m. Unmanned Traffic Management (UTM) is a traffic management system for uncontrolled operations that is separate from ATM development and will ultimately identify services, roles and responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling the management of low-altitude uncontrolled drone operations [21]. The UTM is complementary to the Air Traffic Management (ATM) system, which has been fully digitalized incorporating AI-based features facilitating automation.

There has been an integration of drone traffic into the existing airspace.
The air taxi is equipped with a communication system facilitating communication with terrestrial networks, airborne networks, satellite networks, and aeronautical communication systems. It is utilizing a state-of-the-art Integrated Communication, Navigation and Surveillance (ICNS) system, which is a result of the SESAR3 JU project. It is a central part of the hyperconnected ATM, which is visualized in the flight deck [10].

The hyperconnected ATM use both dedicated aeronautical communication facilities and commercial networks, like mobile and satellite networks. This means that the air taxi can take advantage of mobile services based on the 3GPP standard. Nevertheless, the pilot has at all times access to the aeronautical communication providing safe communication and navigation.

The air taxi is climbing from 150 to 500 meters leaving behind the majority of drones that operate at altitudes up to 150 m. However, there is high activity in the airspace and the pilot has to be alert when managing the eVTOL and responding to information presented on the screen as the autopilot is in operation.

The eVTOL has a license that allows it to fly at any altitude. But it needs to coordinate the flight plan with the ATM system, which is fully digitalized, to get clearance for the specific route. The ATM system provides the position of other aircrafts such as unmanned aircrafts, air taxis, airplanes as it is a full fledged ICNS system.

Established requirements on aviation safety in combination with national security concerns raise a number of critical issues related to commercial operations of air taxis, eVTOLs, unmanned aircrafts and drones that have to be handled and approved by the competent authorities. A new regulatory framework is in place which guarantee aviation safety, specifies which measures should be done for flight planning, flight approval, tracking and procedural interfaces with air traffic control.

The security issues are handled by the designated authorities. The result is a fully automated system which features integrated interfaces with both manned and unmanned aviation, and has full operational capability over the airspace.

The previous no fly zones in the Stockholm area have been opened for innovative air mobility with eVTOLs and unmanned aircrafts facilitating a new market to develop as the Swedish Transport Agency currently only allow drones to fly up 120 m if they do not have special permits. However, the authorities have the option to temporarily close the airspace for this traffic in case special conditions apply [11].

How to navigate flights above and around city airports? The eVTOL is equipped with transponders and an array of cameras placed all around the aircraft, which monitor its surroundings and feed data into the avionics system. The flight deck presents the relevant data for communication, navigation and surveillance in a user-friendly way.

The eVTOL has an autonomous piloting software with an intelligent, camera-based system for visual positioning, landing guidance, traffic detection, and hazard avoidance, which interprets data inputs from ADS-B, and radar.

The communication system in the flight deck is supported by hyperconnected ATM functionalities potentially integrated within the avionic system and covered by the 3GPP standard. The communication system builds on QoS (quality of service) with guaranteed bandwidth, geographical positioning data, and identification facilitating advanced API exposure [15].

The operation of the eVTOL generates an extensive amount of data from sensors, transponders and other equipment, like for example positioning data from GPS, Air Traffic Control (ATC) query to air traffic control, transponder reply, query for traffic alert and collision avoidance system (TCAS), surveillance system (SURV), Terrain Awareness and warning system (TAWS), Weather Radar (WXR) System, including the predictive Windshear Detection (PWD). The eVTOL is using available mobile networks (4G, 5G, 6G and beyond depending on what is most suitable for the purpose), including satellite communication systems (SATCOM) to establish connection with proprietary and private networks, internet and data clouds.

It requires add-on sky network with dedicated spectrum with e.g., up tilt for antenna and high-resolution beam management [22]. A further option for the eVTOL could be to interact with V2X (vehicle-to-everything) communications systems as for terrestrial vehicles. The eVTOL is connected all the time facilitating it to access data from the cloud computing infrastructure and other data sources instantly.

The eVTOL's communication system is considerably more advanced compared to general aviation airplanes, like smaller and private planes [23]. The eVTOL has several options to handle command and control including aircraft communications addressing and reporting system (ACARS), which means that there are fall-back solutions as well as a possibility to differentiate between different classes of communication.

3.2.4 Flying by the airport

The eVTOL continues to raise to 1000 m and above. The pilot manages the flight professionally and do the climbing gradual as the trip continues over the northern part of Stockholm. The pilot manages the vehicle comfortably with the support of advanced cockpit integrating the hyperconnected ATM functionalities with a screen in flight deck that identifies other objects and analyze any potential problems that would require adjustment of the agreed flight plan. The pilot aims to reach 3000 m and establish that altitude as the target for the cruise to Uppsala.

How to navigate above and around Arlanda airport? The eVTOL passes close by Arlanda on the way which means that the pilot must be alert on activities in the airspace in the vicinity of the airport. Activities of commercial aviation could require the eVTOL to adjust its course as a safety measure. The interaction with other flying vehicles: airplanes, eVTOLs are handled by the ICNS system which is part of the hyperconnected ATM system, highly automated providing the pilot with solutions to problems that occur along the route.

The eVTOL monitors the trajectories of aircrafts in the air, and the AI based system handles it automatically, generating alerts in case anything deviates from the planned route. The air traffic control at Arlanda airport monitors all traffic in the airspace, which means that the system monitors the air taxi's journey from Stockholm to Uppsala through an automatic control system for the airspace. A growing business has been established for flying taxis to fly people to and from Arlanda to residential and business areas around Stockholm.

The eVTOL is connected to a terrestrial mobile network, which has been adjusted to provide coverage for flying objects by tilting antennas, and in some cases use antennas directed towards the airspace. Given that the eVTOL has an excellent reception of the radio signals, and the system is handling potential interference and prioritize which base station should be used as it is a connected aircraft. The mobile operators provide dedicated slices for aviation services in order to provide accurate QoS levels including latency at agreed levels according to service layer agreements (SLA) between the air traffic provider and a network operator. Into 2030+, several value chains can occur.

The in-flight entertainment system on the eVTOL provides high capacity WLAN access consisting of an aggregation of radio signals from terrestrial mobile networks (4G, 5G, 6G and beyond), and satellite networks. This provides limitless connectivity for the in-flight entertainment system enabling immersive communication applications.

The operations of the eVTOLs are subject to extensive regulation in order to guarantee safety in the air as well as on the ground. There is security regulation for vertiports to limit the risk of people interfering when eVTOLs are landing or taking off.

How is the interaction between flying vehicles and nearby radio base drones controlled/regulated? The eVTOL is equipped with Airborne Collision Avoidance System II (ACAS II), which reduce the risk of mid-air collisions with aircrafts or flying objects and serves as a last-resort safety net irrespective of any separation standards.

Network operators that use flying base stations are obliged to manage them by remote pilots in order to safeguard that they do not interfere with other flying objects. The eVTOLs are equipped with sensors, transponders and other equipment in order to avoid any collision with other flying objects.

3.2.5 The cruise

The eVTOL is equipped with a fly-by-wire (FBW), which is a control system that uses computers to process the flight control inputs made by the pilot or autopilot and send corresponding electrical signals to the flight control surface actuators. This is necessary because the eVTOLs' have too many effectors to control manually, and they need to add stability for at least some of the flight states. This means that software has become a vital part of the commercial aerospace certification process [24].

The ATM system consists of several subsystems like Air Traffic Control (ATC), which contains everything that enables planes to communicate directly with each other, or through a control tower. The primary goal of ATC is collision prevention, which requires communication and radar systems. There is global communication between vehicles [24]. Moreover, the Flight Control System (FCS) enables one plane to take-off, stay in the air and land. A fully electronic FCS with an all-electronic interface, it sees a computer controlling all an aircraft's moveable surfaces, sending messages through digital cabling [24]. Furthermore, numerous electronic navigation and landing aids exist to assist with weather, collision avoidance, automatic flight control, flight recording, flight management, public address, and entertainment systems [24].

The eVTOLs will make things simpler by alerting pilots about the most important data point as they occur. Key avionics data sets specific to eVTOLs will include available battery power, available range, motor temperatures, and motor speeds [24].

The passengers enjoy the flight with a nice view as well as excellent in-flight services. The passengers are offered services for immersive communication, like virtual meetings with family and friends. It is also possible to complete some work duties during the flight. The family have used the onboard WLAN and not been aware of which technology or networks that have provided the communication links.

The pilot has had a nice ride as the flight deck have provided accurate information and only been asked to intervene in a few instances, where the pilot has been forced to interact and make operational decisions.

3.2.6 The descent and landing

The flight has proceeded according to the flight plan and the eVTOL is approaching Uppsala, which means that it is time to prepare for landing. Given that the vehicle is built for vertical take-off and landing it is a question of a gradual decent to lower altitudes from the cruise altitude of 3000 m down to 500 m and then further down to around 150 m before approaching the vertiport, taking into consideration other activities in air. The eVTOL is programmed for a landing at the vertiport located just south of Uppsala University Library, Carolina Rediviva.

At the same time as the flight is due to land there is a rock concert ongoing close by Uppsala University. The rock concert has attracted a massive crowd generating a strong demand for connectivity. One of the operators has sent up a temporary base station in a drone to handle the increased mobile data traffic. The flying base station is circling at an altitude of 150 m providing a boost to the mobile network and is operated by a remote pilot located at the network operation centre (NOC).

Given that the base station is in the U-space and with operation of the U-space traffic management it is present in the surveillance system, and should therefore not cause any obstacles for other activities in the airspace around Uppsala.

The eVTOL is equipped with an integrated autopilot in the flight deck, which is instructed to land at the specific place as the coordinates have been programmed. The system is based on intelligent software with a camera-based system for visual orientation and positioning, landing guidance, traffic detection, and hazard avoidance. The landing progress smoothly and touch down takes place 24 minutes after

take-off in Stockholm. The pilot thanks the passenger for traveling with Space City and welcomes them back.
The passengers exit the eVTOL and take their bags with them and leave the vertiport Carolina. They walk towards the University Library where they will meet their family friend who is studying in Uppsala. The family have enjoyed the trip and look forward to a relaxing day in Uppsala.

The pilot completes the flight plan report by filling in the information that are requested by the carrier and authorities. It is time to recharge the batteries and undertake the mandatory checks in order to prepare the vehicle for the next flight, which is going to the archipelago east of Norrtälje.

3.3 Consequences

Altogether, a number of things have to happen and there needs to be a fundamental shift of the regulation for the airspace in order to facilitate the described flight for the eVTOL. It has to be permitted to fly with eVTOLs in central Stockholm and Uppsala, which requires that restrictions decided by the Swedish Transport Agency, the armed forces and the Swedish security services have to be eliminated [11]. This would have a fundamental effect on the management of the aviation traffic, which has to be addressed in order to guarantee a safe and reliable air traffic.

The current regulation stipulates that it requires special permission from the air traffic control to fly in the Arlanda control zone, which stretch 5 km from the airport's runways. This means that the regulation has to change and the competent authorities must allow flying vehicles closer to the airport in order to facilitate cost effective flights to Arlanda with eVTOLS. This could give support for an air corridor between Stockholm and Uppsala [11]. Moreover, it requires that the safety for the operation of commercial aviation at Arlanda airport has to be guaranteed, which demand that the management of the airspace is working properly, with functioning fall-back solutions.

The competent authorities have to allow construction of vertiports at attractive locations in order to make it possible to provide services for passengers. It will require social acceptance for the localization of vertiports, increased activity in the air with unmanned vehicles and eVTOLs. Given that this requires considerable investments there has to be a meaningful customer demand that could support this development.

In order to meet the demand for increased communication from the digitalization of the airspace the aviation sector aims to maximize the use of available communication networks for communication that does not require the highest level of security [10]. This is echoed by Eurocontrol, which state that aviation has been using significant amounts of safety protected spectrum for many years and essentially for free, and coordinated efforts must be made to modernize aviation communication, navigation and surveillance (CNS) systems. More resources need to be devoted to tackle spectrum inefficiency to prevent channel saturation, which make it difficult to transition to more modern systems [25].

The hyperconnected ATM system comprise the Integrated Communication, Navigation and Surveillance (ICNS) systems which facilitates smooth air travel with AI supported flight management. The expectation is that the hyperconnected ATM combines avionics systems with 3GPP based systems which could result in integrated communication systems with carrier class. However, this would require that the aviation sector with Eurocontrol and the mobile communications industry collaborates and agrees to establish common standards. This requires that security concerns could be solved in an acceptable way. Although this is a vision of the EU Commission it would require extensive development work, in combination with a breakthrough for collaboration between several industry sectors and authorities.

Given that the hyperconnected ATM integrates connectivity from mobile and satellite networks with aeronautical communication systems it will make it possible to meet the growing demand for data communication and maintain high level of safety and security [10]. It is underscored by Eurocontrol, which state that many legacy systems are operating at full channel load with little flexibility left in frequency bands to accommodate growth [25]. Part of the system is also an Internet Protocol Suit specifically developed for the aeronautical sector.

This development has been driven by the fact that the aviation systems struggle to meet evolving operational requirements [25]. Moreover, the aviation industry regard the costs associated with the deployment of combined mobile, satellite and aviation systems to be lower compared to developing new solutions that use protected spectrum, both in terms of development and deployment of the air-ground infrastructure and in terms of operational costs [10].

To provide coverage for the air management communications system suitable for lower altitude platforms up to 3000 m a number of options could be considered and it raises a number of questions.

- Will this require DME/ILS etc. to be provided by 3GPP systems or other systems: e.g. Air Traffic Control(ATC) query to air traffic control, transponder reply, query for traffic alert and collision avoidance system (TCAS), surveillance system (SURV), Terrain Awareness and warning system (TAWS), Weather Radar (WXR) System, including the Predictive Windshear Detection (PWD)?
- Are there other air management communication systems that could be open for using 3GPP systems?
- Will public safety/national security organizations put requirements on 3GPP systems to provide positioning services, as a second source compared to GNSS systems for aerial platforms?
- How will geofencing be integrated into ATM systems? How will UAM and ATM interact in a situation where there would be a decision that involves both systems simultaneously?
- How is the handling of LOS versus BVLOS aerial platforms?
- Is there a need for traffic and collision rules?

The ATM systems must have possibilities to send updated flight plans to lower altitude platforms to secure coordination between aerial platforms in real-time. Shall UAM/ATM systems have the right to stop flights by taking direct command of aerial platforms? Systems for Communication, Navigation and Surveillance (CNS) has in aviation been regarded as three domains for ATM, navigation and surveillance for handling the airspace.

An important task for the SESAR3 JU project is to establish one integrated CNS (ICNS) environment. This includes all current CNS technologies used for ATM, and those needed to support U-space, IAM (innovative air mobility), RPAS integration (remotely piloted aircraft system) and HAO (higher airspace operations). The ICNS should facilitate all airspace users to inter-operate safely, while reducing costs and the environmental impact through rationalization and multi-use of existing and developmental technologies [9].

This integration should, according to the EU Commission, include technologies from other domains than aviation, such as the telecommunications and the space industries, and handle increased connectivity through digital communications as well as the more conventional elements. Research, development, and demonstration under this action should address both technological issues and the specific performance and certification requirements of all relevant technologies that arise from the evolving U-space and IAM domains [26].

3.3.1 Airspace integration

The U-space regulatory package is in force in Europe since January 2023. U-space is a set of new services relying on a high level of digitalization and automation of functions and specific procedures, supported by AI, designed to provide safe, efficient and secure access to airspace for large numbers of unmanned aircrafts, operating automatically and BVLOS.

The EU Commission underscores that aviation moves from a human-centric system, where safety ultimately depends on pilots and air traffic controllers, towards an information-centric system, where highly automated aircraft can fly safely based on information provided by and through mobile telecommunication networks. As the aviation and mobile telecommunication converge around connectivity, the EU Commission underscores that the need for ICT standards will increase in aviation.

This is particularly the case in the field of drones and unmanned aircraft traffic management solutions, which is a laboratory for digital aviation solutions. The implementation of U-space will enable UAS (unmanned aircraft system) operations in urban environment in safer and efficient manner and having due regard to other societal acceptance aspects such as environment, privacy and security [26].

The integration between manned and unmanned traffic in the same airspace will be initiated, inside and outside the dedicated U-space. One of the objectives of the existing ATM and Standardised European Rules of the Air (SERA) is to avoid collisions between aircrafts. SERA is built on the principle of “see and avoid” which is used by the pilot to avoid mid-air collision.

The integration of drones in the airspace calls for new rules designed specifically for new entrants. In the first stage, the airspace for drones is separated from the airspace used for manned operations to then in a second stage achieve a full integration of both, allowing all airspace users like manned and unmanned, as well as IAM and regular air traffic, but also operators of state, including military, manned and unmanned aircraft to safely and freely operate within the same airspace or transit between airspaces [9. The EU Commission intends to adopt amendments to the Standardised European Rules of the Air and the ATM/Air Navigation Services Regulation to safely integrate drone and piloted eVTOL operations [9].

The EU Commission underscores that U-space service providers should be able to capitalize on the existing mobile telecommunication technologies and standards, such as those resulting from the Aerial Connectivity Joint Activity which is a collaboration by Unmanned Traffic Management and mobile communication entities aimed to promote interchange and understanding between the aviation and mobile communities, the purpose being to enhance information sharing and avoid incompatibilities between those groups.

The use of U-space solutions and operational concepts for a more automated ATM should also be considered [9]. The Commission will continue to promote coordinated research on integrated Communication, Navigation and Surveillance technologies to ensure the convergence between ATM and U-space environments [9].

3.4 Spectrum

Although assignments of spectrum for mobile communication are national decisions in Europe they are dependent on international decisions. Firstly, spectrum is defined by allocations agreed by WRC's updating the ITU Radio Regulations as well as harmonization implementing decisions made by the European Commission, supported by regulatory and technical studies performed within CEPT/ECC. This means that spectrum bands in practice are assigned for various applications with harmonized conditions, which establish a common usage of spectrum which EU member states are obliged to implement following identified market demand.

Existing spectrum licenses for mobile communication do not normally include any explicit restriction from using assigned spectrum above ground for HAPS/HIBS or other flying base stations. But the ITU's Radio Regulations have restrictions in the aeronautical mobile services for several of the harmonized spectrum bands for IMT (International Mobile Telecommunications), e.g., the 800 MHz and 2.6 GHz bands (see Table 1 below).

Such restrictions with respect to the aeronautical mobile service, involving aeronautical stations (typically an airport) and aircraft stations (typically an airplane), made sense and were reasonable with the technological and society developments relevant at the time. Restrictions concerning the aeronautical mobile-satellite service in frequency bands allocated to satellite services in the Radio Regulations are less frequent.

Eurocontrol, a pan-European, civil-military organization dedicated to support European aviation, protects the interests of the aviation community through the involvement in ITU working groups and WRC. Eurocontrol states that aviation must improve its use of spectrum by dedicating more resources to technological enhancement to avoid costly problems in the years ahead [25].

The aviation industry does not expect to get access to additional spectrum allocated for aeronautical services, and is focused to use already allocated spectrum for aviation (aeronautical radio navigation or aeronautical mobile) more efficiently.

Given that radio communication is essential for the aviation industry with communication for both ground-to-ground but also ground-to-air-to-ground, i.e. between aircraft and air traffic control access to spectrum is vital. ICAO handles spectrum issues on a global level for the aviation industry and has over the years played a significant role at World Radio Conferences (WRC).

The SESAR 3 JU project has, so far, not expressed any request for additional spectrum but is determined to maintain access to spectrum that have been allocated and harmonized for aeronautical use.

The aviation sector uses a broad range of communication systems and techniques, which use various frequency bands. IATA underscores that aviation depends on access to an adequate and predictable allocated radio spectrum, which is a limited and valuable resource required for flight, airlines and traffic management operations.

Frequency assigned for aeronautical services are more or less exclusively set aside for communication, navigation and pilot supporting systems, of which many are considered to have safety of life status. It should be noted that it is common that civil and military flight share spectrum resources in various aspects. The relatively close sharing and cooperation concept between civil and military in Sweden is not that common in the rest of Europe.

The EU Commission underscores that frequencies used by satellites are coordinated in compliance with ITU procedures, ensuring that harmful cross-border interference is prevented or minimized. The ITU maintains a register of assigned frequencies and satellite orbits. ITU procedures do not extend to the selection and authorization of satellite services, which is managed at the national level. The growing number of satellite projects has increased the complexity and boosted the volume of new satellite system filing submitted to ITU.

Consequently, WRC 2023 will further consider the development of the space ecosystem to facilitate new applications and frequency bands for space services. Moreover, based on the growing interest for space to ground services the FCC in the US has proposed a new regulatory framework to facilitate innovative collaborations between satellite operators and terrestrial wireless companies. These partnerships leverage the growth in space-based services to connect smartphone users in remote, unserved, and underserved areas [26].

The mobile industry underscores that it has demonstrated its potential to generate economic value and social benefits through its use of allocated spectrum. Regulators strive to make decision regarding spectrum allocation that support an efficient use of spectrum for the net benefit of society.

In order to facilitate for mobile operators to use their spectrum licenses to provide services via HIBS/HAPS and enable coexistence of terrestrial and stratospheric point-to-point links with HIBS/HAPS regulatory measures are necessary to be implemented. This could be done through adjustments of license conditions as well as the Radio Regulations, which aim to prevent harmful interference between different radio services and between the different radio systems of different countries.

If it should be allowed to use allocated spectrum at higher altitudes close to neighboring countries the current restrictions in ITUs Radio Regulations concerning the use of frequencies from aeronautical mobile has to be removed. This will require technical adjustments to avoid interference in mobile networks in order to align flying base stations to the existing grid of base stations.

The following table, which is not exhaustive, presents the main frequency bands used in aviation, mobile communication and satellite. The table shows that the sectors over the years have been allocated spectrum for their various needs. It is based on the frequency plan for Sweden, but to a large extent reflects the situation in Europe as ITU's Radio Regulations to a large degree determine how spectrum is allocated, and later on may be assigned.

The table below show that the primary spectrum for aeronautical are found in the frequency bands 960–1215 MHz, 4200-4400 MHz, and 5030-5150 MHz. Satellite communication use various frequency bands from 1 GHz up to 50 GHz to transmit and receive signals. Terrestrial mobile services have access to spectrum in all or main parts of a number of different bands such as 694-960 MHz, 1710-1980 MHz, 2110-2170 MHz, 2300-2400 MHz, 2500-2690 MHz, and 3400-3800 MHz.

Frequency band MHz	∑ MHz	Sector	Application	Comment
108-118	10	A	Instrument Landing System (ILS), localizer, VOR (very high frequency omnirange station) and GBAS	Radio aeronautical navigation
118-137	19	A	Air ground communication	Voice communication

329-335	6	A	Instrument Landing System (ILS) glide path, glideslope	Radio aeronautical navigation
694-960	266	M	Mobile	Partly block licenses, except aeronautical mobile
960-1215	255	A	Distance measuring equipment (DME)	Radio aeronautical navigation
1559-1610	51	S	Satellite navigation system	Galileo, GPS, Glonass
1710-1980, 2110-2170	330	M	Mobile	Partly block licenses
1980-2010	30	S	Satellite	MSS UL
2170-2200	30	S	Satellite	MSS DL
2300-2400	170	M	Mobile	Partly block license
2520-2690	170	M	Mobile	Block licenses, except aeronautical mobile
2700-2900	200	A	Radio aeronautical navigation	
3400-3800	400	M	Mobile	Block licenses, except aeronautical mobile
3800-4200	400	S	Satellite	FSS DL
4200-4400	200	A	Radio aeronautical navigation, radio altimeter	Used in aircrafts
4500-4800	300	S	Satellite	FSS DL
5030-5150	120	A	Microwave Landing System (MLS)	Radio aeronautical navigation, satellite based
6700-7100	400	S	Satellite	FSS UL
8750-8850	100	A	Doppler NAV	
10700-12750	2050	S	Satellite	FSS/BSS DL
12750-13250	500	S	Satellite	FSS UL
13750-14500	750	S	Satellite	FSS UL
17300-18100	800	S	Satellite	FSS UL
18100-19700	1600	S	Satellite	FSS UL
19700-21200	1500	S	Satellite	FSS/MSS UL
21400-22000	600	S	Satellite	BSS DL

24250-27500	3250	M	Mobile	Available, but not necessarily fully assigned
27500-30000	2500	S	Satellite	FSS/MSS UL

Table 1: A non-exhaustive list of frequencies for aeronautical (A), terrestrial mobile (M) and satellite (S) usage

The use case example (in section 3.2 above) describes a flying taxi that is well equipped with communication systems and uses a number of spectrum bands. Below follows a summary of communication solutions for air traffic services:

- **Mobile (mobile service)**: Allocations with possibilities to introduce terrestrial systems capable of providing electronic communications, including wireless broadband usage.

- **VOR (Very high frequency omnirange station)** is a short-range radio navigation system for aircraft, enabling aircraft with a receiving unit to determine its position and stay on course by receiving radio signals transmitted by a network of fixed ground radio beacons. It uses frequencies in the 108-118 MHz-band. VOR became the standard air navigational system used by both commercial and general aviation, until supplanted by satellite navigation systems such as GPS.

- **VHF radio** beacon used in aviation, usually in conjunction with an instrument landing system (ILS), to give pilots a means to determine position along an established route to a destination such as a runway. The ITU Radio Regulation defines a marker beacon as a transmitter in the aeronautical radio navigation service, which radiates vertically a distinctive pattern for providing position information to aircraft.

  Aeronautical voice communication is also done in other frequency bands, including satellite voice on Inmarsat, Globalstar or Iridium, and high frequency voice. Usually these other frequency bands are only used in oceanic and remote areas, though they work over wider areas or even globally.

- **DME (Distance measuring equipment)** is a radio navigation technology that measures the distance between an aircraft and a ground station by timing the propagation delay of radio signals in the frequency band between 960 MHz and 1215 MHz. DME systems are used worldwide, using standards set by for example ICAO and EASA. Some countries require that aircraft operating under instrument flight rules (IFR) be equipped with a DME interrogator; in other words, a DME interrogator is only required for conducting certain operations.

- **A radar altimeter**, also called a radio altimeter, electronic altimeter, reflection altimeter, or low-range radio altimeter, measures altitude above the terrain presently beneath an air- or spacecraft by measuring how long time it takes for a beam of radio waves to travel to ground, reflect, and return to the craft.

- **Doppler NAV** is a self-contained aircraft navigation system that uses Doppler effect radar interaction with the earth in dead-reckoning calculations to navigate. It has to a large degree been replaced by GPS navigation, but GPS signals are unavailable in parts of the world, and they can be jammed or disrupted by hostile attacks or atmospheric conditions. Doppler navigation works independently, giving flight crews accurate, jam-resistant guidance and velocity data without interruption, but it only works effectively at relatively low altitudes.

- **ACARS (Aircraft communications addressing and reporting system)** is a complete air and ground system, consisting of equipment on board, equipment on the ground, and a service provider. It is a digital datalink system for transmission of short messages between aircraft and ground stations via airband radio or satellite. The protocol was designed by the Aeronautical Radio Incorporate (ARINC) and deployed in 1978, using the Telex format. On-board ACARS equipment consists of end systems with a router, which routes messages through the air-ground sub-network. The ground equipment consists of a network of radio transceivers managed by a central site computer.

- **FSS (fixed-satellite service)**: A radio communication service between earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases, this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radio communication services [28].

- **MSS (mobile-satellite service)**: A radio communication service: between mobile earth stations and one or more space stations, or between space stations used by this service; or between mobile earth stations by means of one or more space stations. This service may also include feeder links necessary for its operation [28].

- **BSS (broadcasting-satellite service)**: A radio communication service in which signals transmitted or retransmitted by space stations are intended for direct reception either through individual or community reception by the general public in the broadcasting-satellite service [28].

3.4.1 The 3rd Generation Partnership Project (3GPP)

Frequencies specified for 5G NR for terrestrial use are found in [29]. In 3GPP Rel -17, the following frequency bands have been specified for satellite communication: [30]

- n255: 1626.5-1660.5 MHz (UL), 1525-1559 MHz (DL) FDD
- n256: 1980-2010 MHz (UL), 2170-2200 MHz (DL) FDD

In Rel-18, 3GPP is working on introducing bands in the so-called FR2, which was originally specified as 24.25 GHz to 52.6 GHz that partially overlaps with the satellite frequencies in the Ka-Band (17.7 GHz – 20.2 GHz for space-to-ground and 27.5 GHz – 30 GHz for ground-to-space). Furthermore, there is a proposal, under discussion, to define a band, which uses DL: 2483.5 MHz – 2500 MHz for the downlink and 1610 MHz – 1626.5 MHz for the uplink.

Direct air-to ground communication is using the spectrum 1900 MHz-1920 MHz and 5855 MHz-5875 MHz [31]. For UAVs, e.g., drones, the operation has been within visual line-of-sight using license-exempt ISM bands (2.4 GHz and 5 GHz). In November 2022, ECC approved ECC/DEC/(22)07 [32]. When implemented in a country, it is allowed for mobile operators in that country to use aerial UEs (drones) in their networks, supporting use cases beyond visual line-of-sight:

- Conditions for using Aerial UEs (drones) in the bands 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2 GHz, and 2.6 GHz.
- The 3.5 GHz band was not included, but should be assessed within 3 years.

Furthermore, in the UK, a UAS/drone Operator Radio license was released in January 2023 [33]. It permits the use of mobile and satellite technologies while requiring the specific agreement of the network operator(s). No transmission is permitted in the 2.6 GHz mobile band.

The importance of spectrum for 6G is put forward in e.g., [34]. Standardization work is already on its way both in 3GPP and ITU-R. ITU-R is currently working on the trends for technology development and the ITU Vision for IMT-2030/6G. It is expected that the 3GPP specification of 6G will be finalized by 2028, and the ITU IMT-2030 standardization by 2030, thus spectrum should become available accordingly.

Spectrum availability can be achieved in different ways or a combination thereof; supported through ITU allocations, regional decisions containing harmonized conditions (e.g. EU) or decisions on a per country basis. Whichever method is pursued, harmonization of the selected frequency bands on a global or regional basis could be key to unlocking economies-of-scale and provide numerous benefits to consumers and enterprises across many markets.

3.4.2 World Radio Conference (WRC)

Given that WRC is the vehicle that ITU uses every three or four years to determine spectrum allocations and if necessary revise the Radio Regulation, which is the international treaty governing the use of the radio-frequency spectrum and geostationary-satellite and non-geostationary-satellite orbits it is relevant to highlight this when discussing spectrum policies. Preparatory work for WRC 2023 is ongoing. ITU state that WRC 2023 will further refine the space ecosystem to facilitate new applications and frequency bands for space services.

The agenda item 1.4 is looking to consider HAPS mobile services in certain frequency bands, besides 2.1 GHz, already identified for IMT: 694 MHz-960 MHz; 1710 MHz-1885 MHz and 2500 MHz-2690 MHz. Moreover, WRC will discuss spectrum for 6G (IMT 2030 and beyond) but it is aiming for WRC 2027, for which the agenda will be discussed and decided under agenda item 10 during WRC 2023.

Spectrum is on the agenda for WRC 2023, e.g. with the following agenda items (AI):

- AI 1.2 – to consider identification of the frequency bands 3 300 MHz-3 400 MHz, 3 600 MHz-3 800 MHz, 6 425 MHz-7 025 MHz, 7 025 MHz-7 125 MHz and 10.0 GHz-10.5 GHz for International Mobile Telecommunications (IMT).

- AI 1.3 – to consider primary allocation of the band 3600 MHz– 3 800 MHz to mobile service within Region 1 and take appropriate regulatory actions, in accordance with Resolution 246 (WRC-19).

- AI 1.4 – to consider, in accordance with Resolution 247 (WRC-19), the use of high-altitude platform stations as IMT base stations (HIBS) in the mobile service in certain frequency bands below 2.7 GHz already identified for IMT, on a global or regional level.

- AI 1.5 – to review the spectrum use and spectrum needs of existing services in the frequency band 470 MHz–960 MHz in Region 1 and consider possible regulatory actions in the frequency band 470 MHz-694 MHz in Region 1 on the basis of the review in accordance with Resolution 235 (WRC-15).

3.5 Regulatory challenges

The previous sections have raised a number of aspects and issues with relevance for regulation and policy for aviation, terrestrial mobile communication as well as satellite communication. They could be grouped into five issues, which gives a base to formulate regulatory challenges that arise with the development of communication system that combines airspace and non-terrestrial networks with integration of terrestrial networks.

The five issues are the following:

- Institutional structure and competent authorities
- Technology development
- Spectrum management
- Cyber security and related national aspects
- Future market, competition, and business models

3.5.1 Institutional structure and competent authorities

The exploitation of the airspace require collaboration between different sectors, industries and international regulatory bodies in combination with forward looking policy makers. 3D networks with multilayered architecture requires an interplay between telecommunications, aviation, and space industries. These three sectors have over the years been competing fiercely for access to spectrum and of which two also have competed to provide services to companies, the public sector and consumers.

The aviation industry is facing a number of challenges as their communication systems are mature, with a fairly low rate of technology development, experiencing saturation in parts of the spectrum allocated to aeronautical services. Currently, aviation is moving into an information centric environment with the digitalization, which calls for higher efficiency of the use of airspace with connected aircrafts and the emergence of a wide variety of unmanned and manned flying objects, like drones and eVTOLs [107].

The aviation industry consider networks provided by terrestrial telecommunication operators as an interesting alternative for communication that are not mission critical or strictly safety related and thereby could be offloaded from their legacy systems as it is more cost effective compared to develop new propriety systems for the aviation sector [10].

This research project has identified that it is vital to renew the currently static practices that are established in the three sectors; that it is necessary to consider how future communication systems could contribute to a sustainable development; that it is an opportunity to address the timely and flexible utilization of emerging technologies with novel, innovative business models and preventing harm to the public.

In order to advance the development it would be desirable if this research project could inspire to collaboration concerning the use and development of regulatory regimes, e.g. by:

- Establishing regulatory sandboxes to examine new regulatory practices such as test different licensing and certification regimes with a mix of regulation.
- Aligning regulations as far as possible.

- Mixing of crossover regulations where appropriate.
- More frequent reviewing of license and certification regimes .
- Examine effects and responsibilities regarding cyber and national security at an early stage.

Altogether, these issues indicate that policy makers and regulators need to be involved in order to better adapt to an increasingly rapid societal development and consider what could be done in order to handle sector-wide issues:

- What could policy makers do regarding the institutional structure to facilitate a constructive collaboration between the three sectors: space, aviation and terrestrial telecommunication? This could for example relate to the set-up of regulatory structures and how responsibilities are divided between different authorities regarding regulation of spectrum, airspace operations and security aspects.

3.5.2 Technology and standardization development

The 3rd Generation Partnership Project (3GPP) completed the standardization of the first global fifth generation (5G) wireless standard in its Release 15 in mid-2018 [35]. The 3GPP organizes its work in releases with a continuous numbering scheme. The work and specifications are divided into three main areas: system architecture, core and terminal, and RAN. The 5G New Radio is a new radio access technology developed by 3GPP for 5G. Each release evolves the capability of the specifications. After completion of the Rel-15 baseline, the first evolution step of 5G systems was finalized in Release 16. New releases are backwards compatible, so that older terminals can function in upgraded networks and vice versa.

3GPP adds functionality that is required to satisfy increasing demands on existing services, for example higher data rates for mobile broadband or to satisfy requirements of new services, use cases and deployment options, such as public safety applications and relaying. However, features are typically specified in a service- and use-case agnostic manner, which means that vendors and operators can determine how to use and combine the specified features.

After completing a Rel-15 study on scenarios and channel models for NR to support NTN, 3GPP continued with a follow-up Rel-16 study on solutions for adapting NR to support NTN. The main objective was to identify a minimum set of necessary features enabling NR support for NTN. This included architecture, higher-layer protocols, and physical layer aspects.

The outcome of the study is documented in the 3GPP Rel 16 study report [36]. NTN (in its wider sense) has become an umbrella term for networks that involve flying objects [37]. The NTN family includes satellite communication networks, high altitude platform systems (HAPS). Air-to-ground networks was also originally within the NTN umbrella, but has since been split out as a separate work in 3GPP. UAV (drone) support is separate to the NTN framework.

The NTN work in Rel-17 introduces new network topologies into the 3GPP specifications [38]. These topologies are based on high-altitude platforms (HAPS), Low Earth Orbit (LEO), Medium Earth orbit (MEO) and geosynchronous orbit satellites (GEO). NTN complements terrestrial networks with network coverage in remote areas over sea and land where terrestrial coverage is absent.

The work done by 3GPP addresses NR, Narrowband- Internet of Things (NB-IoT) and LTE for Machine Type Communication (LTE-M), and it will thereby facilitate 3GPP NTN-based mobile broadband (MBB) and massive IoT services from Rel-17 and onwards (final completion of the radio requirements part of the specifications for NB-IoT and LTE-M will be done in Rel-18). The main challenges identified in Rel-16 and addressed in Rel-17 are related to the mobility and orbital height of the satellite.

In addition to NTN, in Rel-18 3GPP plan to add functionality to support drones (known as uncrewed air vehicles, UAV). This functionality is mainly built on support for UAVs in the 4G LTE specifications, but with some additions for 5G. Unlike NTN, in which the UE is on the ground and the BS is in the air, in the 3GPP specifications UAVs are UEs and are served from base stations on the ground.

HAPS are airborne platforms that can include airplanes, balloons, and airships. In the 3GPP NTN work, the focus is on high altitude platform stations as International Mobile Telecommunications base stations, known as HIBS. A HIBS system provides mobile service in the same frequency bands used by terrestrial mobile networks.

Air-to-ground (ATG) networks aim to provide in-flight connectivity for airplanes by utilizing ground base stations (which are likely to be dedicated for ATG service) communicating to specialized UEs that are mounted on the fuselage of the aircraft. Data to the users is then distributed from the ATG UE to users inside the aircraft using other means. The inter-site distances between the ground stations are much larger than those of terrestrial mobile networks.

In networks with two or several altitude components, the interconnection and integration of terrestrial mobile networks and non-terrestrial communications have to expand future by implementing innovative technologies, which could be possible by paying attention to the trends identified within ITU-R [28]. Regardless of the origin of a new or improved technology it has to support seamless interconnectivity with non-terrestrial networks, including satellite, HIBS and UASs.

Key technologies for this purpose may consist of some of the following: software defined networks, network virtualization, network slicing, AI supported optimized and automated network management, edge computing and free space optical communications. All will be considered in the context of the development of the next generations of mobile telecommunications systems, e.g., 6G including components to connect the sky [28]. The procedure where satellite operators register a satellite network via the NRA to the ITU aims to ensure that satellite networks that are in operation do not cause harmful or unacceptable interference.

With the expected increased activity in the lower and higher airspace as well as in space the velocity in reference to earth becomes an important issue due to various effects of hand-over scenarios and Doppler shift that may impact the quality of communication. GEO satellites follow the angular velocity of the earth and moves in approx. 27000 km/h. More challenging, LEO satellites, not following the earth's rotation, move even faster as they are closer to the earth mass center of gravity. However, concerning airspace components in an integrated network similar issues are much less of a challenge.

In addition, there are some obvious physical limitations with satellite components in an integrated network. One is related to latency in the communication, which have a major impact on the extent of bidirectional real time applications that can be offered with a good enough QoS. The orbits determine the latency for satellite communication. A GEO satellite account for a approximately 480 millisecond (ms) latency round trip time while a LEO satellite in an orbit around 400 km would account for a latency around mid single digit ms and the latency round trip time for HAPS/HIBS is a few ms. The latency for the latest mobile generations are in the low single digit in ms.

Altogether, this provides as basis to formulate the following questions that are of relevance for factors that determine the technological development.

- What could standardization bodies do regarding the institutional structure to facilitate a constructive collaboration between the three sectors: space, aviation and terrestrial telecommunication?
- Aerial platforms have not reached commercial volumes as interference with terrestrial networks could be a problem. How could this problem be handled in order to pave the way for increased use of aerial platforms like base stations on low altitude drones and HIBS?
- The establishment of 3D networks with multilayer architecture is a challenge that 6G-SKY aims to overcome. What could policy makers do in order to facilitate this development that paves the way for these networks by 2030?
- Given that latency is a critical QoS feature of 5G it could be assumed that it will also be an important parameter for 6G which aim to establish multilayer architecture. How will satellite services fit to this ambition?

3.5.3 Spectrum management

Spectrum could play a vital role when used in communication networks to bridge connectivity divides. But the lead times for regional and international organizations establishing or contributing to spectrum regulation are commonly very long. This is also the case for the formation of principles that set the scene for spectrum management as well as it is characterized by a high level of inertia, and affected by boundaries between different sectors or domains.

Altogether, this makes spectrum management and spectrum allocation to cumbersome processes. In order to change this and strive to obtain the most beneficially out of the attractive asset spectrum and make it possible to act in an opportunistic way a comprehensive shift on policy level is essential. However, taking into consideration that frequency assigned for aeronautical services are more or less exclusively set aside for communication, navigation and pilot supporting systems, of which some are considered to have safety of life status.

Given that spectrum is a limited resource and demand for spectrum increase spectrum sharing has become more common and may contribute to such a shift. There are different approaches to spectrum sharing, like for example shared access schemes, tiered-based spectrum access systems, light licensing model and jointly owned radio access networks where allocated spectrum is shared.

The European Communications Office (ECO), which support the European Conference of Postal and Telecommunications Administrations (CEPT), is working on issues related to spectrum sharing. The ECO held a workshop in June 2021 named “Spectrum sharing for the digital ecosystem towards 6G” focused on the current status and future strategic challenges for studies, techniques and regulation to enable shared access to spectrum, which could be relevant to examine. Altogether, it underscores that spectrum sharing has to be an integrated part of any spectrum policy.

Predictability and investment security must be offered without granting exclusive spectrum licenses under possessive-like conditions. Similarly, mechanisms, such as commercial markets, political decisions, comprehensive coordination processes or something else, that make it possible to access spectrum for business like circumstances independent of radio communication service or domain. There could be a risk that collaboration and progress are hampered. Altogether, given the immense importance of spectrum the following questions address some of the key features:

- The established practice and regulation for the global, international and national availability of spectrum could be described as a robust, transparent and predictable mechanism. However, the emergence of 3D networks which cross national borders and stretch from the ground through the aerospace calls for a more dynamic access to spectrum and improved spectrum sharing without undermining safety of life status for some critical communication systems, with a well-known radio environment over time. What could policy makers do to handle these challenges?

- Given increased demand for spectrum from different stakeholders it will require a larger degree of spectrum sharing which will require compromises for all involved parties and a differentiation of the criticality of some systems. How should this issue be addressed and what steps are necessary to take in order to facilitate seamless access to spectrum and spectrum sharing among different actors and among different industries?

3.5.4 Cyber security and related national aspects

Customers in eVTOLs do not only worry about their own physical safety but also about data security both regarding communication and how this could impact the management of other activities in the airspace.

Cyber security should prevent data breaches, cyber malicious activities and cyber-attacks of communication networks and malicious use or control of the flying vehicles. This could be done by encryption of data communication from the eVTOL through hardware and software solutions. The cost impact could be medium and would potentially be generated from securing and monitoring the communications network and/or establishing a private command and control communication link.

As a possible extended part of terrestrial networks for mobile communication systems flying objects (base stations) may be considered in the context of national security in the same way as purely terrestrial networks that already may serve aerial user equipment (terminals). The Swedish Post and Telecom Authority (PTS) has adapted the assignment procedure to the changes in the Act (2003:389) on Electronic Communication (LEK), which came into force on 1 January 2020.

The changes mean that PTS considers national security when assigning licenses to use radio transmitters in base stations. Hence, PTS must consult the Swedish Security Service and the Swedish Armed Forces in matters relating to licenses to use such radio transmitters in accordance with Chapter 3 LEK before the authority can decide in such matters. Similar procedures can be expected to be in place in many other European countries. In the case of Sweden, the terminals are covered by a license exempt regime in line with relevant European harmonization.

Let alone security and safety issue for traditional aircrafts and other flying objects the issue of cyber security, as well as a more physical security and safety dimension, is of great concern as a possible extended part of terrestrial networks for mobile communication systems with flying base stations may be considered in the context of national security in the same way as purely terrestrial networks that may serve aerial user equipment. This could also involve satellite communication and data processing in cloud solutions in the airspace.

Systemic and widespread disruptions of communication networks have extensive consequences for users, companies and the society at large, which means that vulnerabilities and security related to hardware, software, and processes becomes a problem. This have led to that mobile and fixed networks are of strategic importance for society. The national regulatory authorities have therefore been assigned the responsibility and power to ensure that communication networks are secure and resilient with high level of availability and confidentiality for the users.

A number of different measures are available to mitigate cyber security risks of networks. It could for example be measures that aim to prevent unauthorized control or manipulation, unauthorized attacks. Or physical protection of critical components and sensitive parts of the networks. It could also be measures that safeguard national sovereignty and control based on national security risk assessments. Another option is to assess the risk profile of suppliers of critical and sensitive parts of networks. This calls for risk mitigation plan in order to safeguard that networks are trusted.

In a similar way as there has been an extensive policy debate around security issues related to 5G and cyber security in general the development and future deployment of multilayer networks raise a number of security issues, which have to be considered in the development work. Although the development of the future generations could aim to base this on the approach of security by design it has to take into consideration a wide range of security issues already from start.

Moreover, the future network is expected to involve artificial intelligence (AI) and machine learning (ML), which raise questions of national or EU control and how it is managed. The extent of data is growing and with more advanced services like immersive communication and holograms issues of data protection and privacy becomes imminent.

This means that the project has to take data protection and privacy rules into consideration, like the general data protection regulation (GDPR) and e-Privacy Directive. GDPR sets the obligation to process personal data in a manner that ensures its security, including for preventing unauthorized access to or use of personal data and the equipment used for the processing [39].

Altogether, this underscores that security issues has to be an integrated part of the design and architecture, which is highlighted in the following questions:

- The established practice and regulation for regional and national overall considerations effecting cyber and national security have to be included at an early stage in business and technology development. Security aspects have to be weighed in the same way as environmental aspects with the objective of establishing a more realistic view of business opportunities and utilization of technological innovation from the very beginning of such development. What could policy makers do to handle these challenges?

- What measures should policy makers take in order to address the security challenges with multilayer networks, like for example risk mitigation plans in order to safeguard that networks are trusted?

3.5.5 Future market, competition and business models

This section has raised regulatory challenges related to institutional structure and competent authorities, technology development, spectrum management, cyber security and related national aspects. This has generated a number of policy questions that need to be addressed. But in order to realize the premises of the future communication systems they have to respond to a demand from residential and corporate customers as well as the public sector.

Competition has been the driving force for the liberalization of the communication market triggering market actors to invest in network infrastructure and services. Currently, connectivity has become a perquisite for the digital transformation, which implies that it is also a potential concern for policy makers and regulators in order to safeguard competition, support investments and innovation.

From the regulation and policy perspective, 6G needs to be developed for differing regulatory frameworks related to aspects such as spectrum regulation, market power, data access, ownership and use, and requirements set for platforms, digital markets, services, and AI [40].

This study takes a broad scope in order to identify factors that will determine the future communications market. Focus is on three sectors, aviation, satellite and terrestrial telecommunications, that over time should find new schemes for collaboration in order to pave the way for future communication services.

The combination of an aviation sector in digital transition, which experience increased data demand, a satellite sector looking for new businesses and a mature terrestrial telecommunication sector eager to exploit new opportunities could provide a foundation for them to join forces and establish solutions for 3D networks with a combination of airspace and non-terrestrial networks with the integration of terrestrial networks. Future 3D networks could potentially provide connectivity to the unconnected, as well as support aerial uses.

Two important businesses for satellite companies, primarily using the geostationary orbit, are transmission of broadcasting and fixed satellite services for the public sector and professional users. But the breakthrough for streaming video have weakened the previously profitable business model for broadcasting in conjunction with that new players enter the satellite market with ambitious projects using lower orbits.

The satellite industry underscores that governments should provide assurances of stability and spectrum availability. The inclusion of satellite in the 3GPP standards have led to more interaction between terrestrial operators and satellite companies, underscoring that the satellite industry is very interested to explore new opportunities crossing domain boundaries.

While policy decisions regarding satellites to a large extent are dependent on a regulatory framework established and matured on an international level terrestrial telecommunication issues are primarily handled on a national level supported by international harmonization and standardization.

6G-SKY aims to advance the communication system beyond the current generations. The ultimate outcome of this ambition will be determined by how the sixth generation of mobile communications will be received and how it will be adopted by users, companies, the public sector and the society at large. A decisive factor that will influence this are social and economic benefits.

The digital transformation requires access to communication infrastructure, which enables the use of services for consumers, businesses and the public sector. Although, it is still early days for the development of 3D networks, which in itself raises extensive technical challenges it also raises questions regarding the future market, competition and business models that have policy implications.

AI is as an integrated part of communication and computing in the multilayer architecture. The aim is to integrate terrestrial, airborne and space-based systems, which should enable unlimited communication in all dimensions. This is further reinforced by the integration or rather convergence between the physical and cyber worlds. All this creates an extensive ecosystem with a number of different categories of players, which should facilitate a wide range of services.

It will require that the 6G vision "systematically address business and societal opportunities, value creation and capture mechanisms, and competitive advantages of 6G as antecedents for economic feasibility and successful commercialization in the digitalizing business ecosystem" [40].

6G has a wider ambition compared to previous mobile generations by adding e.g. the altitude dimension and incorporating various communication systems that converge. For further description see chapter 5 use case analysis.

In line with the harmonized regulation and ethical guidelines presented for AI, a value-based policy for trustworthy 6G can be envisioned, building on transparency, fairness, accountability, robustness, safety, human agency and oversight, privacy, and data governance as values. To achieve user- and developer-centric 6G, the technical processes and related decisions need to be explained to stakeholders [40].

The potential economic benefits that 6G could result in will depend on how its services will be used in different sectors in society, how the integration of the physical and cyber world will play out, to what extent it could facilitate new kind of services that brings value, and whether the public sector could provide new and transforming services.

It will be important for policy makers and regulators to monitor this development in order to safeguard that 3D communication systems facilitate competition at all levels, and that it provides meaningful connectivity to customers in areas that are not well served today. Moreover, it underscores that the future communication market is expanding beyond the current ecosystem involving new kind of players that serve customers at all altitudes. Altogether, this generate questions that policy makers need to handle in the years to come.

- The continued digital transformation requires investments in communication infrastructure. Multilayer networks require integration of terrestrial, airspace and non-terrestrial networks which implies that a number of different players have to join forces. How will this influence competition on the wider communications market in the future?
- Assuming that the aviation sector succeeds to establish the hyperconnected ATM, which use terrestrial telecommunication and satellite networks besides legacy aviation systems it will constitute a major shift on the wider communications market. How will this affect competition and future business models? Will this be run by established operators or create opportunities for new entrants? What kind of business models will this facilitate?
- Will aerial platforms play an important role to connect the unconnected? Will this be dependent on public investments?

4 6G Use case segments for digital airspace and NTN

4.1 Use case framework for combined digital airspace & NTN networks

6G-SKY has defined the following use case framework for digital airspace, see figure 9 below:

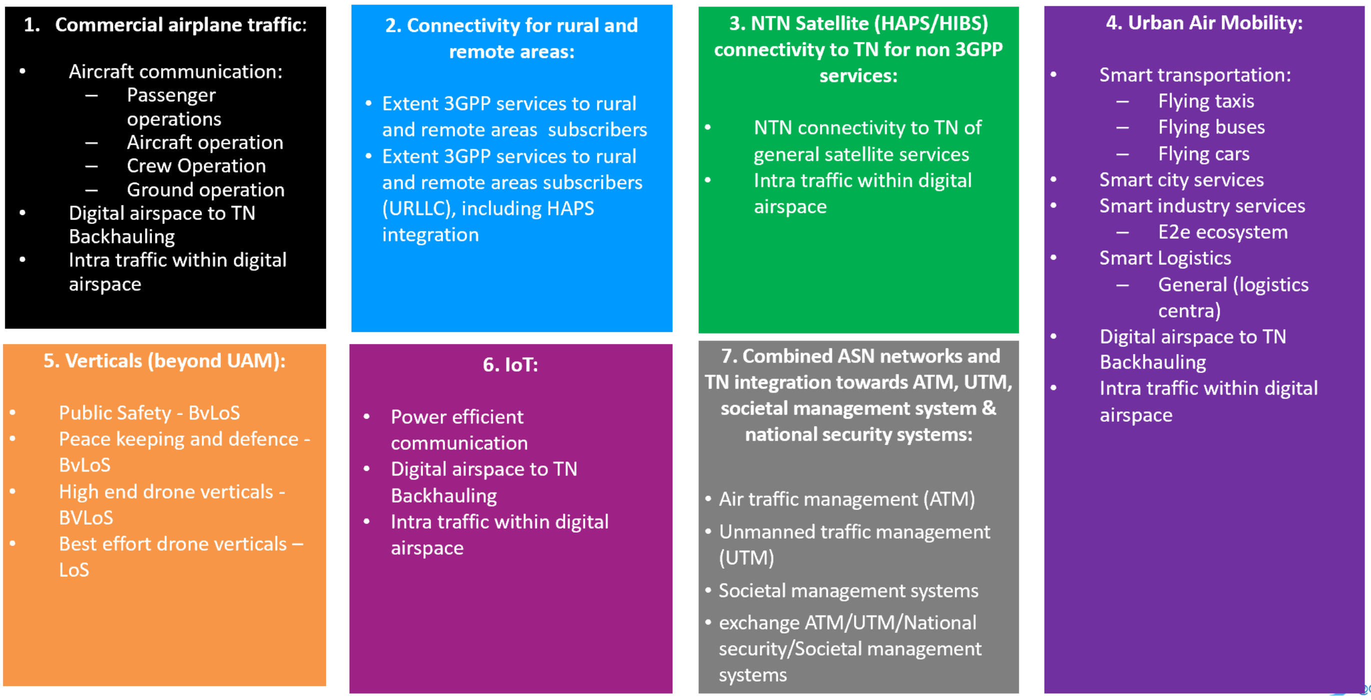

Figure 9: Use case segments for combined ASN networks.

The use cases are defined from a commercial perspective and are all supported by digital airspace. In this report, the following 7 use case segments will be further analyzed and described:

1 Commercial airplane traffic - The vision for communication towards the use case segment for commercial traffic is that you should be able to gain the same experience on an airplane as if you were using the UE on ground level. This also means that basically all 6G innovation areas will be valid.

2 Connectivity for rural and remote areas - This use case segment is not considered to be served with same level of performance compared to areas with a higher density of wireless traffic. Here, satellite and HAPS systems can complement 3GPP connectivity.

3 NTN Satellite (HAPS/HIBS) connectivity to TN (for non 3GPP services) - A use case segment that employs the wireless network as a connection point and transport of satellite related data traffic.

4 Urban Air Mobility (UAM) - This use case segment is expected to be impacted largely by 6G innovation. One reason for this is that a large portion of the population is already in cities and urbanization will increase. Smart cities will trigger many other smart solutions and the use case segment will benefit of a tight TN and combined ASN networks integration forming a digital society.

5 Verticals (beyond UAM) - Addresses the use of aerial platforms for different industries beyond those served by Urban Air mobility. As part of the ongoing value chain re-engineering, industries are looking into how to use aerial platforms to enhance and innovate value chains. One example is electricity infrastructure owners that want to inspect the electricity infrastructure by using drones.

6 IoT is a special use case segment with special requirements on both devices and the network.

7 Combined ASN networks and TN integration towards ATM, UTM, societal management system & national security systems - A use case segment that will interact with all aerial platforms but also towards different types of management systems.

4.1.1 Commercial airplane traffic

Commercial airplane traffic has basically two types of traffic types: links to and from the airplane, as well as communications related to the internal body of the aircraft.

Broadband in-flight connectivity services for commercial airplanes can be provided using satellites or direct air-to-ground (A2G) communications. Satellite-based in-flight connectivity is already offered to airplane passengers today. Satellites have the advantage of offering global coverage that can span over both land and sea, which make them suitable for intercontinental flights. However, satellite-based in-flight connectivity services suffer from a limited system capacity and long latency [6]. The alternative approach is based on A2G communications using cellular technology to establish direct connectivity between terrestrial base-stations and aircraft. A2G networks offer a larger system capacity and shorter latencies than satellites but their coverage is limited to over land or along the coasts.

In the ICARO project, four service operation areas were defined for in cabin communication, i.e services for:

- Passenger operation
- Aircraft operation
- Crew operation
- Ground operation

Each service operation area has a set of services attached to it. Each of the services can be further innovated with 6G. Below follows a figure showing an overview of services attached to the service operation areas:

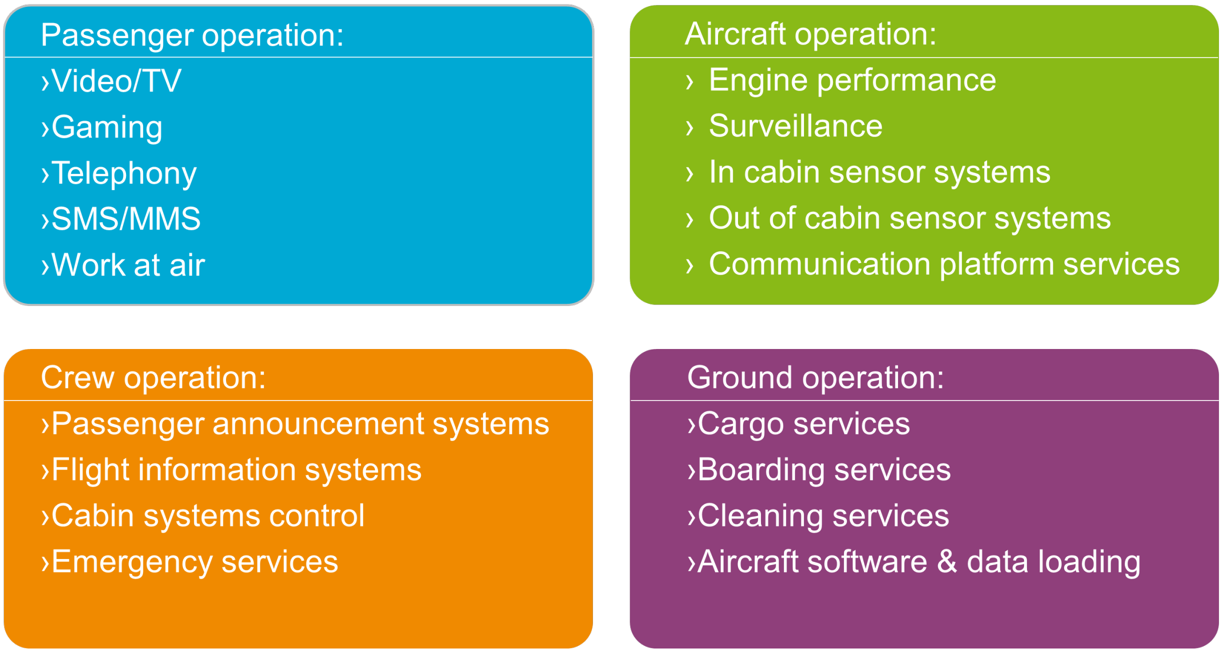

Figure 10: Services attached to service operation areas

4.1.1.1 Passenger operation

In-Flight Entertainment and Connectivity (IFEC) is a growing market and wireless connectivity (nowadays WiFi) is important to a majority of passengers. Passengers may also expect free services on short-haul routes and rebook with an airline that offered quality inflight connectivity. IFEC primarily addresses passengers and includes Internet access as well as on-board services, e.g., entertainment videos provided by the airline. Beyond 6G passenger (or crew) devices, 6G may play a significant role in the overall IFEC infrastructure.

4.1.1.2 Aircraft operation

Communications for Operations and Maintenance embraces manifold communication activities during flight and ground operations, as well as (regulated) maintenance actions for aircraft. At an airport, for instance, multiple interactions appear between the aircraft, airline, and the airport ground services. For example, recorded sensor data can be downloaded from the aircraft for predictive maintenance. As 6G becomes a worldwide standard and with a rich ecosystem, it can facilitate these communication and sensing activities on a broad scale.

Safety-Critical Communications, e.g., between ATC and pilot, is currently supported by legacy systems such as VHF or L-band satellite systems operating in dedicated and protected spectrum bands. Activities are undergone to consider public non-safety commercial communication systems as a component of aircraft safety communications, e.g., in the hyper-connected ATM ambitions. 6G emerges in the right time to support such safety-critical communications.

4.1.1.3 Crew operation

Communication systems that can enhance crew operation can both be enhanced and innovated with 6G. Today, passenger announcement systems still use wired solutions for announcing information to passengers. These could e.g., be innovated with wireless headsets and microphones.

Flight information systems can be real-time updated and also tied to individual passengers needs.

4.1.1.4 Ground operation

When an aircraft is on the ground there are many interactions ongoing. All of these interactions can be digitalized and innovated with wireless services.

4.1.2 Connectivity for rural and remote areas

HAPS and satellites can be used to extend connectivity to rural and remote areas and by this work as a complement to wireless networks. Different parts of world have different needs of providing connectivity to rural and remote areas. Digitalization in Europe faces the challenge of requiring network connectivity everywhere and always. Even if most of the world's population is estimated to live in the urban areas, rural areas need to be supported to stay attractive for the people e.g., to be able to produce the food (and other agricultural products such as bioenergy) efficiently and sustainably using smart farming technologies.

Bridging the so-called digital divide is one of the key obligations across Europe. Employing NTN based connectivity services into those areas may be an attractive solution as long as the terrestrial networks do not have a complete coverage.

Another aspect is the world-wide export of products and services, which can greatly benefit from a satellite backbone and service platform. Satellites provide services for maritime users on oceans, islands, mountain districts and sparsely populated areas where it can be an attractive alternative for sparsely populated and remote areas.
HIBS (High-altitude platform stations as IMT base stations) do not replace terrestrial systems but can be seen as a complement. With flying base stations, moving at an altitude of 20-50 km, it is possible to create large macrocells, which can provide a significant addition to coverage, primarily outdoor. HAPS could support a variety of use cases for both developed and developing markets. It could for instance provide enhanced and temporary connectivity over regional areas where the ground infrastructure is broken (or simply over saturated) to provide additional connectivity.

4.1.3 NTN Satellite (HAPS/HIBS) connectivity to TN for non 3GPP services

Satellite and HAPS can also be used for non-3GPP services. Examples include earth observation, disaster management, and critical infrastructure monitoring that are provided by satellites and HAPS.

Particularly, the use case of 6G for future Earth Observation (EO) tasks can be highlighted, where EO entities on platforms (e.g., satellites, HAPS and drones) can profit from high-capacity 6G networking combined with AI-processing (e.g., edge computing) on the platforms and the 6G infrastructure.

6G enables (i) a standard interface to these platforms and (ii) high data rates, which are often needed in imagery applications, and (iii) edge computing, e.g., on NTN low Earth orbit satellites and NTN HAPS.

4.1.4 Urban Air Mobility

It is estimated that about 70 percent of the world's population will be living in the urban areas by 2050 [7]. Hence, there will be a need to exploit the airspace above these metropolitan areas for transportation of goods and people to avoid congestion from an increase in ground-based traffic. The term "smart city" was coined to describe an urban area where networks and services are made more efficient with the use of sensors and digital solutions for the benefit of its inhabitants and business.

According to The United Nations Economic Commission for Europe (UNECE) and the International Telecommunication Union (ITU), a smart city is an "innovative city that uses information communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and increase competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects." Smart city services can include smarter transport networks, upgraded water supply and waste disposal facilities, and more efficient ways to light and heat buildings, monitoring the city's air-pollution.

Urban Air Mobility (UAM) has been closely linked to smart cities and is a concept towards 3D transportation to increase its efficiency in the metropolitan areas. UAM is a new concept to realize the smart mobility in the low altitude airspace in metropolitan areas. UAM provides an alternative to current ground-based transportation systems such as buses and cars, by enabling the transportation of passengers in flying vehicles. But it will also enable flying UAVs/drones that offer surveillance and monitoring services for public safety.

UAM is not only interesting in itself, but also in connection to other evolutions in the society, where it can be integrated with concepts like smart cities, Industry 4.0, and general innovation in transportation of goods and people. As cities grow they also need to automate, digitalize and build smart solutions. Digital airspace can support this transformation by also providing urban air mobility solutions. The emergence of UAM will require the regulation of airspace to ensure safety and to avoid conflicts between flying vehicles.

4.1.5 Verticals - beyond UAM

In recent years, the aviation industry has been experiencing a tremendous paradigm shift. Unmanned aerial vehicles (UAVs), also known as drones, have been used in a wide set of applications such as monitoring, search and rescue and providing wireless connectivity in remote areas. Many of the drones found on the market today are consumer drones, considered as best effort or low-cost drones, and operating in visual line of sight (LOS) based WiFi /WLAN. UAVs operating in beyond visual line of sight (BVLOS), on the other hand, would require mobile communication, which is highly interesting from a 3GPP based communications point of view.

The market for commercial UAVs is estimated to grow, which means an enormous increase in the number of deployed UAVs for different applications and business initiatives. There is an increasing trend in the research and development for UAVs, especially for their connectivity to use them at their full extent. In addition to manufacturing these flying vehicles, wireless connectivity will be required to fully operate them in a large scale and manage the aerial traffic.

Industries are constantly looking into ways for improvements within their fields and a part of Industry 4.0 is exploiting the promising potential of drones. Drones e.g., are now being used extensively for aerial photography, surveillance and 3D mapping, shipping, and remote sensing. It has found a place in almost all kinds of industrial ecosystems. The increasing interest in drones can be attributed to the easy availability of drones in the market, to the minimal change to infrastructure needed when adding them into an existing workplace, and the possibility of reducing manual labor.

4.1.6 IoT

The IoT market represents an interesting and potentially huge revenue stream for the satellite industry with opportunities in many markets, particularly vertical ones addressing the need for machine-to-machine communications with global coverage or in places where terrestrial networks are not deployed such as remote, oceanic or desert areas. It is experiencing a robust growth as companies are continually seeking out new ways to raise productivity while reducing costs. IoT communications can be used in a seemingly endless number of ways ranging from logistical tracking, telemetry, remote monitoring, geofencing, security, scientific monitoring and many others.

Europe has a strong space industry, in particular many companies producing various types of satellites. Combining these space or air-borne devices with attractive IoT services will strengthen the equipment vendors, but also IoT service providers within EU. The solutions proposed in the 6G-SKY project may boost productivity of end users and widen the business of on-ground device providers.

4.1.7 Combined ASN networks and TN integration towards ATM, UTM, societal management system & national security systems

The combined ASN networks market is in many aspects at a very early stage in the hype curve for communications. There are solutions for satellites and commercial airplanes, but the ongoing electrification and digitalization of the society, including digital airspace open up new opportunities to create solutions for communications.

In order to handle the expected growth of aerial platforms, there will be a need for a digital system that can monitor and manage the activities of aerial vehicles and that is scalable as the number of flying vehicles increases. This system is defined as Unmanned

Traffic Management (UTM) and should be included in the future air traffic management system (ATM). Air traffic management will most likely be more automated to cope with all the flying vehicles. Unmanned traffic management will emerge to complement ATM.

Smart cities may put new requirements on communication networks and require communication to and from societal management systems.

Public safety, peace keeping, and defense are foreseen to increase usage of wireless systems, which will require communication support towards national security systems. The international characteristic of 6G-SKY raises a number of security concerns. Security issues related to 6G will be at least as important as for 5G. In the case of Sweden, the Swedish Security Service has set up 16 principles that operators have to comply with for 5G [41]. In 6G more issues will likely occur e.g.,

- Satellite systems controlled by foreign companies could be a security concern.
- Localization of equipment, data processing could trigger security concerns.
- Control over critical resources is a concern for governments and regulators.
- Connecting mobile networks with satellite networks could raise security issues.

5 Use cases segment analysis

6G-SKY has performed a deeper analysis on use case impacts from the following perspectives:

- Analysis of SESAR impacts on use case segments.
- Analysis of 6G Research challenges on use case segments [8].
- Analysis of Services impact on use case segments.

5.1 SESAR impact on use case segments

6G-SKY has reused the defined innovation areas by SESAR and conducted an impact analysis on the defined use case segments (See chapter 5.2). The innovation areas defined by SESAR is summarized in the figure below:

- Airborne Automation
  - Cockpit evolution:
    - Augmented approaches, 4D Trajectory, self separation, make vortex detection and avoidance, video-based navigation system, Future collision avoidance (ACAS-X)
  - U-space
    - Automatic gyros inertial navigation, emergency recovery, dynamic geofencing, detect and avoid
- Ground Automation
  - Evolution of the ground system:
    - Wake separation, 4D Trajectory, complex digital clearances, speech recognition, traffic complexity resolution, assistance for surface movement, role of human, safety nets, runway status and surface guidance, advanced separation management, Intelligent queue management
  - U-space
    - Traffic information, Flight Planning, Dynamic capacity management, automatic deconfliction (Multiprovider)

- Virtualization
  - Virtual augmented reality
    - Approach and landing aids for the cockpit, virtual aids for tower control,
  - Virtual centres
    - Rationalization, contingency, dynamic cross border, delegation of services
  - Remote tower
    - Single airport, multi-source data fusion, multiple and large airports
- Connectivity
  - Cockpit evolution
    - Multilink management, broadband satellite communication (ESA-iris), broadband airport communication, broadband ground communication (LDACS), Cellular link for GA/RC
  - U-space
    - Command and control, tracking and telemetry, vehicle to vehicle, vehicle to infrastructure

Figure 11: SESAR Innovation areas

The SESAR innovation areas are further described in the SESAR ATM master plan. The SESAR innovation areas will drive a change in four phases towards the European digital sky by 2040. 6G-SKY has reused all these innovation areas in the analysis of digital airspace and tried to judge the level of impact: high medium or low, see figure below:

Use cases Segments / Innovation area	Commercial airplane traffic:	connectivity for rural and remote areas:	NTN Satellite (HAPS/HIBS) Connectivity to TN (For non 3 GPP Services):	Urban Air Mobility:	Verticals (Beyond UAM):	IoT	Combined ASN networks and TN integration towards ATM, UTM, societal mangement system & national security systems:
Airborne automation	X	X	x	X	X	x	X
Ground automation	X	x	x	X	x	x	X
Virtualization	X	x	x	X	X	x	X
Connectivity	X	o	X	X	o	X	X
Data sharing	X	x	o	X	X	x	X

Figure 12: Analysis of SESAR impacts on use cases, X = Large impact, o = Middle impact, x= small impact

It is worth noting that our initial analysis indicate that commercial airplanes, urban air mobility, and combined ASN networks and TN integration towards ATM, UTM, societal management systems & national security systems may have the largest impact from SESAR, both in level of impact and from a width of SESAR innovation areas. If wireless systems is used for commercial airplane traffic, users will require the same service level of 6G services as on the ground. In urban air mobility there will be many requirements from smart solutions driving innovation. Management systems will handle requirements from all use case segments and will therefore be required to support the width of SESAR innovations. For IoT the SESAR innovations are expected to have low impacts, which is natural as the main purpose of IoT is to support power efficient solutions. Nevertheless, the requirements for IoT can be minor in impact but of great importance for implementation towards the IoT use case segment.

5.2 6G Research challenges impact on use case segments

HEXA-X 6G aims to tightly couple and enhance the interactions between three worlds:

- The human world of our senses, bodies, intelligence and human values.
- The digital world of information, communication, and computing.
- The physical world of objects and organisms.

These worlds interacts with a set of research challenges defined for 6G by HEXA-X.

The HEXA-X identified research challenges: extreme experiences, extreme performance, connecting intelligence, networks of networks, sustainability, global service coverage, and trustworthiness have been reused for the analysis of impacts on use case segments. The HEXA-X research challenges have been complemented with an additional research challenge: internet of senses. Below follows a figure illustrating the impact analysis from 6G research challenges on 6G-SKY use case segments:

Use case segments / Innovation area	Commercial airplane traffic:	connectivity for rural and remote areas:	NTN Satellite (HAPS/HIBS) for Connectivity to TN (For non 3 GPP Services):	Urban Air Mobility:	Verticals (Beyond UAM):	IoT	Combined ASN networks and TN integration towards ATM, UTM, societal mangement system & national security systems:
Internet of senses	X	o	x	X	X	x	o
Extreme experiences	X	o	x	X	o	x	o
Extreme performance	X	o	o	X	o	x	X
Connecting Intelligence	X	X	x	X	X	o	X
Networks of networks	X	X	o	X	X	o	X
Sustainability	X	X	x	X	X	x	X
Global service coverage	X	o	o	X	o	o	X
Trust worthiness	X	X	o	X	x	o	X

Figure 13: Analysis of 6G Research challenges impact on use case segments,
X = Large impact, o = Middle impact, x= small impact

On the left side, 6G innovation areas are defined: internet of senses, extreme experiences, extreme performance, connecting intelligence, networks of networks, sustainability, global service coverage and trustworthiness.

What is interesting to note is that three of the use case segments will be exposed for large impacts from several 6G innovation areas: commercial airplanes, Urban Air Mobility and combined ASN network communication & TN integration towards ATM, UTM, societal management system & national security systems. For the IoT use case segment, 6G innovation areas are regarded to have low impact. The reason for this is that this area has the focus on minimizing power consumption and prolong the battery life of IoT devices. Any adjustments in functionality, may be small but of large importance to satisfy this use case segment. Small impact does not mean that the impact is insignificant, but just small and in this case expected.

5.3 Services impact on use case segments

6G-SKY has defined a set of service areas connected to use case segments and analyzed the mapping towards use case segments. Below follows a description of the chosen service areas:

Service area	**Description**
Connectivity	Connectivity is a basic communication service that can be offered between aerial platforms and towards users. In this category, connectivity related services can also be added upon the connectivity.
In cabin communication services	In cabin communication services can be used to satisfy passenger operation, aerial platform operations, support crew operation and support ground operation including the interaction with landing platform.

Air platform services	This service category is focusing on services that support the aerial platform and its interaction with other aerial platforms, the network and other areas that requires functionality on the aerial platform.
Electrical services	Aerial platforms will overtime become electrified and will require battery services. This category will handle battery related services from an aerial platform life cycle perspective.
Connected air traffic infrastructure services	Aerial platforms will interact with ATM, UTM, societal management system & national security systems and interchange data. The data can be of different types: user data, control data for communications, and control data for flight operation of the aerial platform.
Advance pilot assistance services	The interaction between the human, physical and digital worlds can advance pilot assisted services including the innovations driven from digitalizing airspace.
Connected goods services	Goods are already today an exploding area. Aerial platforms can be part of providing logistical services and support of connected goods operations.
Fleet management & orchestration services	In logistical solutions, sustainability and economical optimizations can play an increased role for aerial platform route management and control of fleet management operations. Orchestration of these activities can be supported from the networks.
IoT services	IoT devices and aerial platforms serving IoT devices have special requirements to support power efficient operations. Data can be processed in a power efficient way. Data and control traffic for communications can be adopted to prolong battery life at devices and in electrical aerial platforms.

Figure14: Description of services that can be used within use case segments

Below follows a figure showing the analysis of impact on services on use case segments:

Use case segments / Innovation area	Commercial airplane traffic:	connectivity for rural and remote areas:	NTN Satellite (HAPS/HIBS) connectivity to TN (For 3 non GPP Services):	NTN for Urban Air Mobility:	Verticals (Beyond UAM):	IoT	Combined ASN networks and TN integration towards ATM, UTM, societal mangement system & national security systems:
Connectivity (Backhaul)	X	X	o	X	o	x	-
In cabin communication services	X	-	-	X	-	-	-
Air platform services	X	o	x	X	o	x	X
Electrical services (Battery loading)	o	x	-	X	X		o
Connected air traffic infrastructure services	X	x	x	X	o	x	X
Advance pilot assistance services	X	-	-	X	x	-	X
Connected goods services	o	-	-	X	X	-	x
Fleet management & orchestration services	o	-	-	X	X	X	x
IoT services	-	-	-	-	-	X	o

Figure 15: Analysis of impact on services on use case segments, X = Large impact, o = Middle impact, x= small impact

The use case segments with largest impact from services are the commercial airplane traffic and urban air mobility.

6 Flying platforms mapped towards use case segments

6.1 Flying platform description

For the use case segments the following aerial platforms have been considered:

- Drones
- eVTOL
- Airplanes
- HAPS/HIBS
- Satellites

Drones are small to medium sized flying platforms that operate at different altitudes and perform various tasks depending on what application they are designed for. They can for example host base stations for providing temporary communications capacity over a small area, they can be used for observation tasks or for parcel delivery. Also, in the field of Public Protection & Disaster Relief (PPDR), drones can support in various ways. Drones are remotely piloted and may be partially or even fully autonomous and are also referred to as unmanned aerial vehicles (UAV). Depending on the altitude, a distinction is made between low altitude platform system (LAPS) and high altitude platform system (HAPS). The latter is explained in more detail further below. Throughout this project, the term drone is used for a flying platform at rather low altitudes and thus in this case synonym to a LAPS.

An electric vertical take-off and landing (eVTOL) aircraft does not, in contrast to airplanes, rely on a runway. For the purpose of this project, we consider this platform category to include small to medium sized and highly automated aircraft used to carry passengers or cargo at lower altitudes in urban and suburban areas. This is often referred to as urban air mobility and the eVTOL sometimes also as an air taxi. For sustainability reasons, we focus solely on those aircraft that use electric means for power and propulsion but generally the connectivity related aspects could also be applied for example to helicopters with different means of propulsion.

Airplanes are typically large flying platforms that provide transportation services, for passengers and for cargo, over long distances. Airplanes are flying at high altitudes of around 10 km and they typically follow a strict flight plan along coordinated flight trajectories.

HAPS are flying platforms that remain quasi-stationary at an altitude of 20 km to 50 km above a fixed location on ground. There are different airborne vehicles conceivable: Lighter-than-air vehicles such as balloons or dirigibles, light solar fixed wing (FW) HAPS and heavy FW HAPS. They fly well above conventional airplanes and the jet-stream and are only integrated into other airspace users during their ascent and descent phases. In case the HAPS payload performs the functions of a base stations, the term HIBS has been established, which is an acronym for high altitude platform station as IMT base station. Additionally or alternatively the HAPS could also support 5G/6G backhauling functions [9].

Satellites are objects placed into an orbit around earth with the objective of providing communications services or of performing observation tasks. Typical satellite orbits are between a few hundred kilometers and approximately 36000 km above the surface of the earth. The latter orbit can be a geostationary orbit (GEO), where the satellite remains at a fixed location above the earth surface as it moves synchronous to the earth rotation. For all other orbits, also referred to as non-geostationary orbits (NGSO), the satellites are moving continuously around the globe. Depending on the orbit altitude different NGSO are distinguished. Most prominent examples are the low earth orbit (LEO) and the medium earth orbit (MEO), where the LEO altitudes are generally below 1000 km and MEO altitudes cover everything between LEO and GEO [10].

6.2 Mapping of flying platforms towards use case segments

An analysis has been made regarding the mapping flying platforms towards use case segments, see below:

Use case segments / Aerial Platforms	Commercial airplane traffic:	connectivity for rural and remote areas:	NTN Satellite (HAPS/HIBS) connectivity for TN (For 3 non GPP Services):	Urban Air Mobility:	Verticals (Beyond UAM):	IoT	Combined ASN newtorks and TN integration towards ATM, UTM, societal mangement system & national security systems:
Drones				X	X	X	X
Air taxi	o			X			X
Air plane	X			o	o		X
HAPS / HIBS		o	x		o	o	X
Satellites	x	X	X	x	o	x	X

Figure 16: Mapping of flying platforms towards use case segments, X = Large impact, o = Middle impact, x= small impact

It is worth noting that management systems must be able to handle all types of flying platforms.

7 Highlighted use cases

Within the 6G-SKY project there are some examples of use cases that have been chosen to be highlighted and will be further described in this chapter. These use cases reflect possible future actual use cases that will employ aerial platforms and benefit from the combined ASN networks complementing the ground-based networks.

7.1 Logistics centers supported by swarms of drones

7.1.1 Background and Motivation

We consider a special kind of logistics centers, where change between transport modalities of goods takes place, namely between rail- and road transport. Very often such centers are located at the boundaries of urban areas or even in rural areas. The particular scenarios and use cases refer to the Logistic Center Austria Süd (project partner LCAS) as depicted in the figure below.

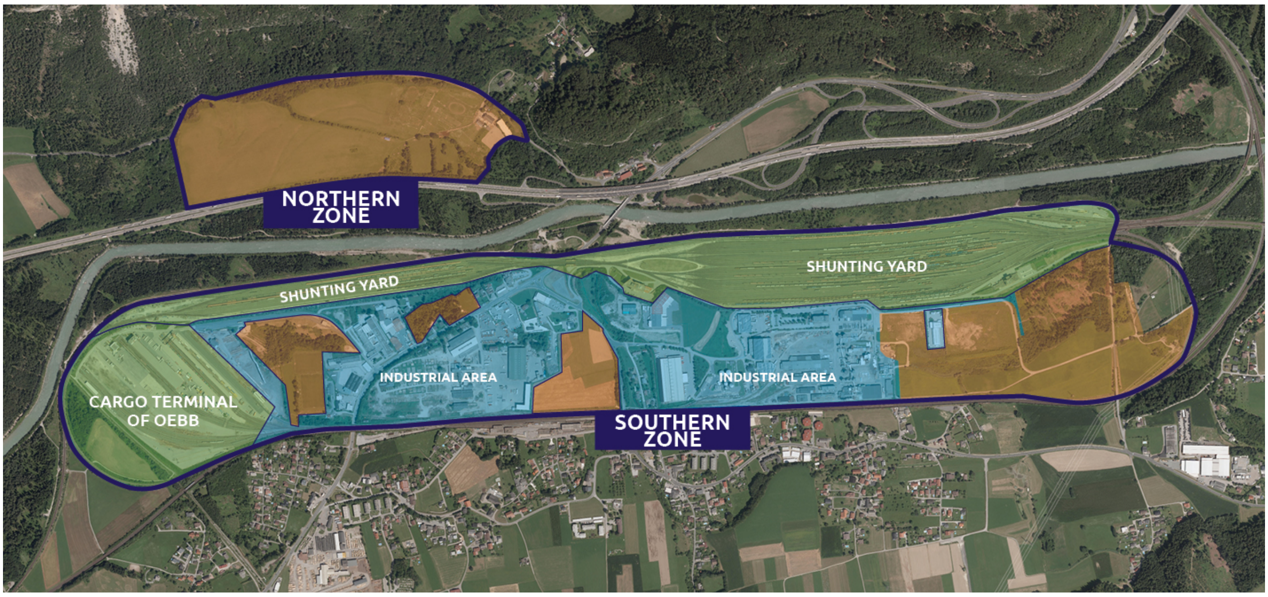

Figure 17: The different areas at LCA-Logistik Center Austria Süd in Fürnitz, Austria (from LCA-Logistik Center Austria Süd and Google Maps).

The current focus is on the existing cargo terminal in "Zone Süd", where containers are shifted from trucks to trains and vice versa to serve the first-/last mile cargo delivery. Currently, the containers are registered manually via unique container IDs when they enter the terminal and booked out when they leave it. This container ID is used to assign containers to wagons in the train or to trucks from different cargo shippers. In the terminal, so called reach stackers (basically diesel trucks with container lifting mechanisms as shown in the Figure 18 below) or cranes load or unload containers on/from trucks or wagons or store them in dedicated areas until they can be further processed.

There is an initial daily plan on trains/trucks and containers coming in, and a GPS system on the forks of the reach stackers is used to report the GPS position of a container when it is stored. . To avoid unnecessary routes of trucks and stackers and unnecessary shifts of containers (so called „dispo lifts“), it is necessary to know about the location of the containers in the storage areas. The information on stored containers (location and container ID) is used by a central systems route planning to show the drivers the way to a particular container the driver selects to handle next. However, this route planning does not include other traffic information (location of trucks, jams, accidents, etc) and relies on the "integrity" of the drivers, meaning that they really pick the container they report to the system (container ID). Such and other events ("uncontrolled movement of containers") result in ambiguities in container locations and therefore sometimes unnecessary routes and dispo lifts.

It is the goal of the the Logisitcs Center to avoid unnecessary dispo lifts and extra miles for trucks and reach stackers in order to reduce energy- and diesel consumption and therefore considerably reduce the CO_2-footprint of the logistics center.

Figure 18: Diesel based reach stackers as currently used at LCAS (Image by ÖBB/Martin Hofmann)

7.1.2 Suggested solution

The idea is to suggest a means of periodic terminal state estimation by a swarm of drones embedded in the 6G-SKY architecture. The drone swarm carries camera sensors to generate data for the status info and at the same time provide wireless connectivity in the terminal. The latter supports D2D communication between drones for swarm coordination, as well as transmission of payload data/information to a base station/data center. From the data positions of the containers can be retrieved, unusual events in the terminal can be detected (accidents, jams, queues, etc.) to improve the current route planning. In this way, energy efficiency can be improved and CO_2-footprint can be reduced. Moreover, throughput times can be reduced.

The suggested idea in short:

- Perodic state estimation of the terminal via periodical aerial imaging (where are the containers and vehicles?).
- Use the information to re-plan routes of vehicles (trucks,reach stackers, etc.) and coordinate the reach stackers (assume that later on autonomous electric vehicles will come in).
- The system shall prepare reliable, adaptive and flexible V2V- and V2I- communication.
- No goal: integrate the system into LCA's current ICT systems and processes and into existing booking platforms (follow up project).

7.1.3 Optimization goals

The optimization goals can be summarized as follows:

- Minimization of dispo lifts.
- Reduction of per day travel distances of the vehicles.
- Reduction of container throughput times.
- Reduction of fuel and energy consumption (that would optimize energy efficiency and CO_2 footprint).

7.1.4 Details of current container shift processes

Figure 19: Schematic sketch (right, by ÖBB/Alexander Sablatnig/Julia Felden) and satellite image (left, Google Maps) of the cargo hub in Fürnitz, Austria.

The figures above show the different areas of the cargo terminal within the LCAS. The container handling from rail to road and vice versa can be described as follows:

#	**Road to Rail**	**Rail to Road**

1	Truck enters terminal (1)	Train enters terminal (4) (cargo list)
2	Truck parks in the P1 area (2)	Cargo list handed over to TSA (for booking in)
3	Document transfer to TSA (3) , data base entry (Container ID, etc.) (booking in)	Reach stacker puts containers to storage spaces (4)
4	Define target for truck within (4)	Truck enters terminal and registers at (3)
5	Driver drives truck to destination in (4)	Truck gets destination within (4)
6	Reach Stacker lifts container from truck to either wagon or storage space in (4)	Truck drives to destination in (4)
7	Container leaves cargo terminal on train	Reach Stacker puts container on truck.
8	Container is booked out	Truck leaves terminal, container is booked out

Figure 20: The container handling from rail to road and vice versa.

7.1.5 Use Cases

Currently, we can identify two use cases in the scenario of container shifting in the terminal:

- UC1: Initial planning (based on received requests before start of a working day).
- UC2: Periodic optimization of reach stacker routes and lifts, as well as truck routes (based on actual status/condition of the terminal and new incoming requests,accidents, etc.).

UC1 is not a part of this project and is considered as a frame condition that does exist. From UC1 we know which containers are in the terminal and which ones that have to arrive or leave in the particular working day.

Name	UC2: Reach stacker and truck route optimization

Short description	UC2 will be triggered by LCAS periodically on demand and will start a fleet of drones with camera sensors to collect data from the hub/testbed. An algorithm will separate objects (vehicles, free/occupied slots, containers, train wagons, etc.). Simulations and predictive algorithms will recalculate optimized routes based on the collected information. In 6G-SKY we will focus on the existing terminal of "Zone Süd". The server that collects data, assesses the hub status, and calculates optimum routes is based at LCAS and another one to test cross hub connectivity will be located at RED. The link can be realized via direct UAV satellite link.
Actors	LCAS, LCAS operator/employee
Trigger	Request for hub status update and optimization for routes.
Initial Conditions	Initial/rough planning of routes available may be available for adaption or planning/routing optimization is done from scratch
Result (incl. success criteria)	energy efficient and CO2 efficient routes/number of lifting steps for execution during the following 30 minutes before re-assessment step. See optimization goals in section 7.1.3 above.
Standard procedure	• LCAS: Give start signal on local server. • UAVs start from dedicated home positions. • Pre-defined and/or random area coverage. • UAVs send geo-referenced pictures to ground local and remote. • Local and remote server assess hub status and calculate best routes/lifting steps. • UAVs return to home positions. • ...

Figure 21: UC2 - Reach Stacker and truck route optimization

7.1.6 Frame Conditions and Requirements

The size of the cargo terminal is about 7ha (roughly 350m x 200m). The number of containers/wagons/trucks processed per day is roughly 100. The terminal operates between 6am and 7pm on working days and from 6am to 1pm on Saturdays. For further requirements, see section 7.2.2 below.

7.2 UAV swarm to support autonomous mobility and infrastructure in rural areas

7.2.1 Background and Motivation

This use case is an extension of the one under chapter 7.1. The idea is to replace the diesel based reach stackers by autonomous electrified vehicles that need to be coordinated in the existing cargo terminal, as well as connecting other areas of the LCAS like the "Zone Nord", which is planned to be an extension of the logistics center, for warehouses with no direct connection to the terminal.

To coordinate the ground vehicles, we suggest a tight coupling of the UAVs and the ground vehicles forming a "mixed swarm" on a common mission, namely optimizing all operations in the whole of the LCAS for energy efficiency and minimum CO_2-footprint. Thus, the drones also become a part of the terminal's IT infrastructure to guarantee connectivity for the autonomous ground vehicles, to provide actual state information of the terminal, and to use the information to coordinate ground vehicles and drones commonly.

The tests are going to be performed together with subcontractors AIRlabs Austria and ALP.Lab, which provide test areas for drone flights and for autonomous vehicles, respectively. As autonomous ground vehicles for moving containers will not be available before the end of the project we will use and modify autonomous vehicles provided by ALP.Lab.

The aim is to measure communication related metrics such as packet loss, delay, etc. for both, control data and camera sensor data from drones and assess the performance of the 6G-SKY architecture. A simple example of the terminals traffic will be mapped to the testbed and performed in the demonstrations. The demo setting has still yet to be defined.

7.2.2 Frame Conditions and Requirements

7.2.2.1 Detection task

The main detection task in all use cases is the detection of containers, trucks and reach stackers, as well as autonomous vehicles (future replacement of diesel-based reach stackers). Reach stackers, trucks and containers are structures spanning over several meters. Containers are standardized in sizes and forms. LCAS mostly uses 40ft-and Low Cube 20ft containers (see e.g., [11]) and truck trailers. The automated vehicles that will be used in the project are in the low meter range. To resolve the structures mentioned, only moderate physical resolution the so called ground resolved distance (GRD) in the range of a few 10 cm is necessary. For container identification, the containers are marked with standardized alphanumeric codes mostly placed on the front, back and sides of the container and sometimes on the top [12].

First measurements have shown that cameras with resolution of around 8MPx are sufficient to account for detecting containers and read their ID for identification (GSD-Ground sampling distance of about 1 cm). The experiments suggest that identification of the container ID can be done at UAV-altitudes up to 30 m. This suggests a configuration where some UAVs fly in higher altitudes (e.g. 80 m) to locate container islands and others in lower altitudes to detect IDs and locate single containers.

During a status update mission, we expect that every UAV generates in the order of 100 images that will be processed on-board. Processed data, as well as compressed images will be sent over the network to a base station. We expect the generation of a few GB of data on the drones per mission. The overall localization accuracy of all objects shall be <= 1 m. The time between image recording and results arriving at the base station is in the order of minutes.

7.2.2.2 Coverage

It is planned to use 4 UAVs and 1-2 UGVs (the latter for the use case to support autonomous mobility). For the demonstrations according to the use case in sec. 7.1 we will focus on a part of the cargo hub of max. 1ha in size. About the same dimensions of the test area is expected to be used for demonstrations according to sec 7.2 (autonomous mobility).

Typical distances between the drones and the UGVs shall be in the range of 10-200 m. The base station shall be within 200 m of the nearest drone. However, detailed specifications on distances will be finally fixed as soon as the way of UAV-UGV collaboration and coordination and the means of communication will be settled.

7.2.2.3 Image data processing and use of information

Image processing will be used to separate container islands, individual containers, reach stackers, and trucks. Container identification will be done via OCR analysis. All associated processing will be done on board of the drones. The positions of the containers with particular container ID will be estimated and sent to a base station at LCAS and at RED (over a cell network or other) for optimized routing of reach stackers and trucks, as well as for reducing cargo lifts. The base station itself will be a standard PC/server comprising the route planning and a yet to be defined rough user interface to plan the UAV mission and to show the results of the state estimation. Along with the positions of the different objects, compressed image data will also be sent over the UAV network to the base station. The requirements for the communication network are as follows:

- Payload data: a few GBs to be sent to the base station within a couple of minutes (relaying-, multi-hop connection between drones assumed).
- Control data (a few 10kB.. per sec.. D2D) with a latency not exceeding 100 ms.
- Outside LCAS communication: above-mentioned payload data over cellular network or satellite (the latter tested separately in Ottobrunn). A similar PC/server as the base station located at LCAS should be mirrored at the premises of RED to show the capabilities of the overarching 6G-SKY architecture.

Networking involving remaining carriers (e.g. HAPS, etc.) will be demonstrated in other use cases.

7.3 Joint sensing, communication and computation in 3D

6G networks should exploit the ubiquitous presence and computational power of communication nodes in ground, air and space. Beyond the network side nodes, each communication user is a potential radio observer of the environment as well as a platform for external sensors, which may use the network for data collection and actuation. Computing resources at the edge of 6G networks permit efficient synchronization, synthesis and cooperation of multiple sites of sensor networks. Regionally distributed data processing and data reduction enable fast control loops and efficient data acquisition.

In 6G-SKY, we focus on use cases where the communication transmitter or receiver involved in monostatic or bistatic radar sensing is on an airborne or space-borne platform or the observed target is in air:

1. The transmitter is on a satellite or airborne platform and a set of base stations on ground act as bistatic receivers. The base stations form beams and observe targets either on ground or in air in a coordinated or individual fashion. Precise timing and known position and trajectory of the satellite platforms, as well as, the line of sight direct signal from the transmitter to receivers permit the ranging of point or surface targets.

Since the transmitter is on a moving platform, the spatial resolution of radar sensing can be enhanced by Doppler processing. The strength, delay and Doppler shift of the reflected signal characterizes the target.

A straightforward use of such a point to multi-point sensing geometry is the detection and tracking of flying objects. Since the receivers are at base stations, which are relatively densely deployed, there is a good chance for transmitter-target-receiver constellation, where the receiver can see the target without background clutter. Hence telecommunication sensing can be a supplementary technique in air traffic management.

2. The reverse geometry of the above sensing scenario is, where the transmitters are the ground base stations and the receivers are either space- or airborne. The receivers may form and scan directional beams towards ground objects. Tracking selected targets require tight synchronization and coordination of transmitters and receivers.

   An example of employing such a sensing geometry is when we map terrestrial targets around fixed ground transmitters like base stations. These transmitters illuminate their surroundings, and the reflections from nearby targets, surfaces can be captured by satellite receivers.

   In this use case we exploit that communication satellites repeatedly follow the same track so by accumulating observations from the same ground segments by multiple satellite runs, we can gradually build up an image of reflective stationary objects on ground. We may look for observations from satellite passes which deviate from the usual image so that appearance of targets, changes in the environment or propagation conditions carries information which is worth to monitor.

3. Simultaneous Localization and Mapping (SLAM) technique in the radio spectrum [42] would also employ the bistatic radar geometry. For example, UAVs with their beamforming communication receivers might scan the environment for specular reflections of terrestrial communication signals and by using the direction, time delay, Doppler frequency shift and signal strength of the direct and reflected signals, the UAV can continuously compute its relative motion and attitude towards the transmitting and reflecting points and hence can navigate even where GNSS service is not available.

4. Both the transmitter and receiver sides are in air or space, which is the classic Earth observing use case. The great number of 6G NTN nodes may provide a special advantage in satellite remote sensing compared to traditional Earth observing satellites. [43] analyzes the interoperability between multiple interferometric synthetic aperture radars, and such operation might be partially emulated by communication satellites orbiting close to each other.

   The primary information in remote sensing is the normalized radar cross section of surface targets, but stereo processing from twin satellites allow precise 3D imaging.
   Other airborne sensing use cases, which involve cooperating targets or flying platforms of 6G terminals are discussed in Section 7.2.

Joint sensing and communication are an emerging concept in 6G that enables reuse of spectrum and hardware for radio sensing and wireless transmission. It is possible thanks to the transceiver structure and signal processing framework [44]. Offloading computing to ubiquitous wireless network infrastructure can enable reduction in latency and pave the way toward joint sensing, communication and computation.

Although it is being investigated in terrestrial networks, different challenges may arise for 3D networks due to different mobility and radio environments. One challenge is the coordination of these capabilities in 3D NTNs and how it may be affected due to the network density and heterogeneity of network devices in the air or space.

In order to enable these functions jointly, unified hardware, resource and protocol design is one approach so that the communication, sensing and computational abilities cooperate [45]. For instance, the sensing information may be used to increase reliability and latency performance of the wireless communication. Communication and computational resources may be optimized in NTN to enhance cooperative sensing.

Thanks to wireless networks, intelligence and computation abilities can be distributed over the network elements. Sensing ability may also result in massive amount of environment data. Hence, we need an intelligent network control and decision framework to integrate sensing, communication and computation capabilities in our 3D architecture and to manage multi-dimensional resources in terms of communication capacity, sensing precision, and computation.

7.4 Safe and explainable AI for adaptive and robust communications

In traditional software engineering verifying the exact functionality of a software algorithm is part of certification. However, translating this idea to machine learning models is complex since the inner processes are nontrivial. There are efforts that are trying to prove mathematically the safety of a model in an operation range.

The recent advances in artificial intelligence (AI) and machine learning (ML) have resulted in the widespread application of data-driven optimization systems. The 6G communication is expected to support ubiquitous AI to help solve problems that cannot be handled by traditional methods. In many cases, the AI system is designed to work with zero human involvement to reduce the operating expense.

Thus, it is critical to design an AI system that can be trusted to work under expected or unexpected circumstances. This is typically referred to as Trustworthy AI. A robust and explainable system should be capable of handling out-of-domain samples and provide solutions understandable by human users.

With the inherent bias caused by human training or data collection, it is challenging to provide an equal quality of experience regardless of where the users are located, when the service requests happen or who the users are. Some of the biases arise from uneven data collected by the operator or biased feature learning system.

To guarantee the equality among all users, an AI system should be able to recognize input biases and take measures when necessary. It may not be possible to completely eliminate the input biases. In this case, explainable AI should be able to understand the reason of biases and take actions to mitigate their influences.

Robustness is another critical aspect of Trustworthy AI, which aims to make reasonable decisions under adversarial perturbations or out-of-domain samples. Adversarial attacks consist of attacking the input data or manipulating the training model to drastically change the explanation maps. Robust AI system should also be able to operate and generate reliable results in unexpected or unsampled situations. Trustworthy AI, with its explanation capability, can provide information to identify the types of attacks and make the end-users easier to defend them against the attacks.

Explainability is central when it comes to designing a Trustworthy AI system. It means that the decisions of the system should be interpretable by the end-user whether in normal or abnormal scenarios. Explainable AI means that the system should provide results that can be understood by a human user how it works. The choice to either trust or not trust the results and following available actions could be taken by the end-users.

To make sure the Trustworthy AI system works, different measures are needed to evaluate the performance and verify the effectiveness of explanations given by the AI system. The possible criteria could be user satisfaction in the view of the end-users, task performance measuring how well the user understands the Trustworthy AI system and trust assessment to evaluate user's ability to decide whether to trust or doubt the outputs of the system.

Another fundamental aspect related to safety of AI systems is data privacy. Data is required to train AI algorithms and how this data is being handled is fundamental to ensure that AI systems can be trusted. One solution to this problem is federated learning. Federated learning (also known as collaborative learning) is a machine learning technique that trains an algorithm across multiple decentralized edge devices or servers holding local data samples, without exchanging them. This approach stands in contrast to traditional centralized machine learning techniques, where all the local data sets are uploaded to one server, as well as to more classical decentralized approaches which often assume that local data samples are identically distributed.

Federated learning (FL) enables multiple actors to build a common, robust machine learning model without sharing data, thus allowing to address critical issues such as data privacy, data security, data access rights and access to heterogeneous data.

The topics highlighted above correspond to different aspects and solutions that are fundamental to ensure trust of AI systems. In addition, it is crucial to ensure that the process of building and deploying AI systems follows a process that can be trusted. This process should consider the aspects highlighted above, but also other aspects that ensure that the developed AI follows the existing regulations.

7.5 Safety and security for flying UEs

6G promises trustworthiness that translates to a holistic security architecture on the network level. While existing security solutions from 5G provide a solid foundation, the cyber-physical nature of 6G-connected aerial vehicles requires a thorough investigation.

In addition to the traditional security attributes of confidentiality, integrity, and availability, access control and non-repudiation, our solution considers that security threats may impact safety (and, thus, human lives) directly. Therefore, a security-safety co-design mindset is crucial.

From the safety aspect, the greatest challenge regarding safe urban airspace operations is the coordination of flight missions comprising both manned and unmanned aircraft. To this end, a complete single source picture of the sky is indispensable. With non-cooperative/malicious UAVs in urban airspace, we foresee the emergence of a UTM Service Provider (USP), which shall be able to obtain information from a drone detection and positioning systems (DDPS) and a ground-based traffic information system-broadcast (TISB).

An implementation of DDPS is proposed to be based on a sensor-fusion system (e.g., radar and passive-RF) to detect and locate any type of UAVs including unauthorized ones, enabling blacklisting and white listing based on customer preferences.

From the security aspect, the proposed novel non-terrestrial network architecture, making use of heterogeneous links, comes with its own security requirements. On top of the inherent challenges in wireless security, we foresee that thwarting spoofing attacks will become a focus point of related security efforts. Such attacks could potentially cripple two major functionalities of the novel architecture utilizing unauthenticated communication protocols: i) advanced localization (via GNSS spoofing) and ii) the above-mentioned drone detection (via ADS-B spoofing).

In addition, UAVs introduce an entirely new set of security challenges: they can be operated either by remote control or autonomously using onboard computers; accordingly, the UAV system is vulnerable to attacks that target either the cyber and/or physical elements, the interface between them, the wireless link, or even a combination of multiple components.

8 6G-SKY demo scenarios

The overall goal in 6G-SKY is to demonstrate the functionality of the developed 6G technology elements and the 6G-SKY architecture on a system level. This will be accomplished in different environments depending on the underlying use cases. We will further develop dedicated hardware necessary for the tests (UAVs, antenna modules). Test procedures, performance metrics and success criteria for each test/demonstration as predefined in WP1 will be detailed in the beginning of WP5. These will be applied to the testing and demonstrations. Particular objectives are:

- Development of dedicated UAV hardware for swarming and antenna modules for use in the tests (Task 5.1).
- In-lab interoperability testing and validation of communication links and applications as used in tasks 5.3 and 5.6 (Task 5.2).
- Evaluation and proof of concept of the results out of the WP 2, 3 and 4. Multi-Technology Connectivity Links and the resilience of the adaptive multi-technology network will be tested (Task 5.3).
- Proof of concept demonstration of networking and swarming technology with a real swarm of UAVs applied to the mobility use case defined in WP1 (Task 5.4).
- Demonstration of safety in Urban Air Mobility and U-space by providing "see & be seen" capability to all types of low flying aircraft including manned aircraft, collaborative drones and non-collaborative drones (Task 5.5).
- Test and demonstration of HAPS-Ground, HAPS-low altitude UAV, HAPS-HAPS and HAPS – Satellite links (Task 5.6).

8.1 Multi-technology network integration

After pre-integration of the different 6G technology elements from the partners in the Fraunhofer lab (antennas and communication links for UAVs, satellites and HAPS), the multi-technology integration in the field and demonstrations will be performed: demonstration of multi-technology connectivity links and resilience and seamless connectivity via terrestrial network (when available) and satellite + mesh network.

We will demonstrate the results of the WP 2 Multi-Technology Connectivity Links and the resilience of the adaptive multi-technology network developed in Task 3.1 by seamlessly switching between terrestrial network (when available) and satellite + mesh network. The connectivity demonstration should also take place when crossing borders to ensure a constant connectivity of the user.

Additionally, key components for safe and explainable AI will be integrated in the demonstration. An online AI algorithm will be shown, which adapts to changing channel and network situations during flights to improve the end-to-end communications quality by operating on network system parameters. The achieved robustness (e.g., improved packet error rates) will be displayed concurrently.

Moreover, a method to ensure explainability will be demonstrated for cases, where the decisions of the AI system need to be validated in hindsight. A candidate case is a hypothetical safety-related incident that is based on alleged poor channel performance. The tests will be performed using the Airbus Helipad in Ottobrunn, Munich, Germany. The helipad and lab-space will be accessible by the partners for the test campaigns. The setup is depicted as follows:

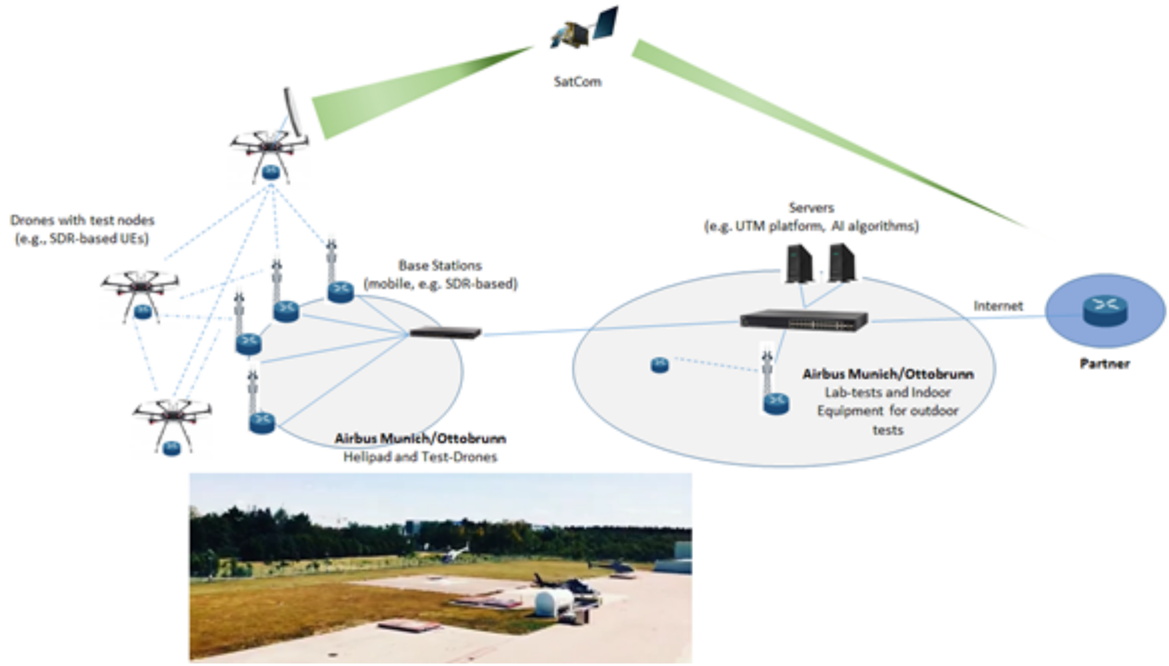

Figure 22: The connectivity demonstration: demonstrating switching between TN and NTN

Four UAVs will be equipped with hardware that provides a terrestrial network connectivity and A2A connectivity. One of the UAVs will also be equipped with an additional satellite connectivity hardware. The network traffic to the individual UAVs will be steered either through the terrestrial base stations directly, or through satellite and HAPS connectivity using the UAV with corresponding hardware as the gateway to the other UAVs through an A2A mesh network. The quality of the end-to-end links in each case, as well as the time taken to switch from one topology to the other will be evaluated.

Out of task T2.2, optimized antennas for the A2G communication for flying vehicles to the test equipment, limited here to Air-Taxis (Airbus) and one ground station, will be provided.

8.2 3D network demonstration with multiple drones flying as a swarm in coordination

The use cases and their background are described in 7.1 and 7.2. We will demonstrate the 6G-SKY architecture including swarms of drones in two situations of the cargo hub use case: 1. with the current set-up at LCAS and 2. Including autonomous ground vehicles. The particular demo scenarios are described in the following:

8.2.1 3D network demonstration in current LCAS-setup

The underlying use case for the demonstration is described in chapter 58. For the demonstration we will use 4 TW drones and a base station. The demo environment will be the Cargo Terminal Süd at LCAS on a typical working day. For the use case demonstration we will observe the number of cargo lifts and distances traveled by reach stackers and trucks during a day. In parallel drones will do periodic state estimations of the hub. Optimized paths and lifting steps will be examined and compared to the current paths and number of lifts.

The energy and CO2 savings will be estimated via simulations of the setup as well as in experiments in the cargo terminal. For the network demonstration we will assess delay: e.g. packet loss rate. In the UAV-based communication network as well as in the outward connection, all connection is used to communicate data for processing at RED also to test the part of the 6G-SKY architecture outside the UAV swarm in this particular demonstration but can e.g., be replaced by satellite or HAPS connection, which will be shown in another use case.

8.2.2 3D network demonstration including autonomous ground vehicles

In this setup we will demonstrate a "toy-model" setup of the cargo terminal assuming autonomous electrified reach stackers are in place. These reach stackers will be emulated via autonomous cars provided by the ALP.Lab innovation lab. The autonomous cars still have to be defined but will be connected to the UAVs in the UAV swarm exchanging telemetric data. In this way, the ground vehicles will be integrated in the coordination loop with the UAVs forming a heterogeneous swarm of autonomous robots/vehicles.

Containers will be emulated via boxes etc. The test environment will not be LCAS itself but a test area connected to either AIRlabs Austria or ALP.Lab. The UAVs will be equipped with the same sensors and data analysis from RED as in the demo in chapter 8.2.1Even if we will emulate a situation at the cargo hub, which is yet to be defined, the aim of this particular demonstration is not to optimize the processes of the cargo terminal itself. We will rather assess the appropriateness of the 6G-SKY architecture (especially the UAV element) for the integration of autonomous ground vehicles into the terminal infrastructure, instead. In other words, the 6G-SKY architecture will be tested and prepared for future integration of autonomous electrified vehicles at LCAS.

Also here, a cell-based link to RED servers will be established for data exchange, which can be replaced by other means of communication (satellite-, HAPS-based, etc.) These other means will be tested within other use cases.

We will analyze particular communication metrics such as latency/delay, packet loss rate and bandwidth and analyze the feasibility for coordinating both UAVs and ground vehicles for the particular LCAS-use case.

8.3 Sense and avoid mechanisms

Between 19 and 21 December 2018, hundreds of flights were canceled at London Gatwick Airport following reports of visual UAV sightings. The London Gatwick incident and similar ones clearly illustrate that coordinating and authorizing flight missions of manned and unmanned aircraft is not sufficient to ensure safe airspace operations.

Coming U-space regulations enforcing geofencing will prevent UAVs from flying unintentionally at restricted locations, but such regulations will not stop non-compliant UAVs and pilots with malicious intent from entering restricted/controlled airspace. Detecting and locating UAVs not broadcasting or providing their location (non-cooperative) is required to ensure a complete, single source picture of the sky in urban areas. Another challenge in this context is then how to convey in real time to manned aircraft that UAVs are present in the airspace.

To remedy the issue with non-cooperative UAVs in controlled airspace and the lack of information sharing between manned and unmanned aircraft, the authors propose that a UTM Service Provider (USP) will obtain information from a *drone detection and positioning systems* (DDPS). An implementation of DDPS is proposed to be based on a sensor-fusion system (e.g., radar and passive-RF) to detect and locate any type of UAV.

To convey the information of non-cooperative and cooperative UAVs to manned aircraft, the authors propose that a USP will be integrated with a ground-based *traffic information system-broadcast* (TISB). An implementation of TISB is proposed by the authors to be based on ground-based low-power ADS-B transmitters and ADS-B receivers enabling information exchange in both directions.

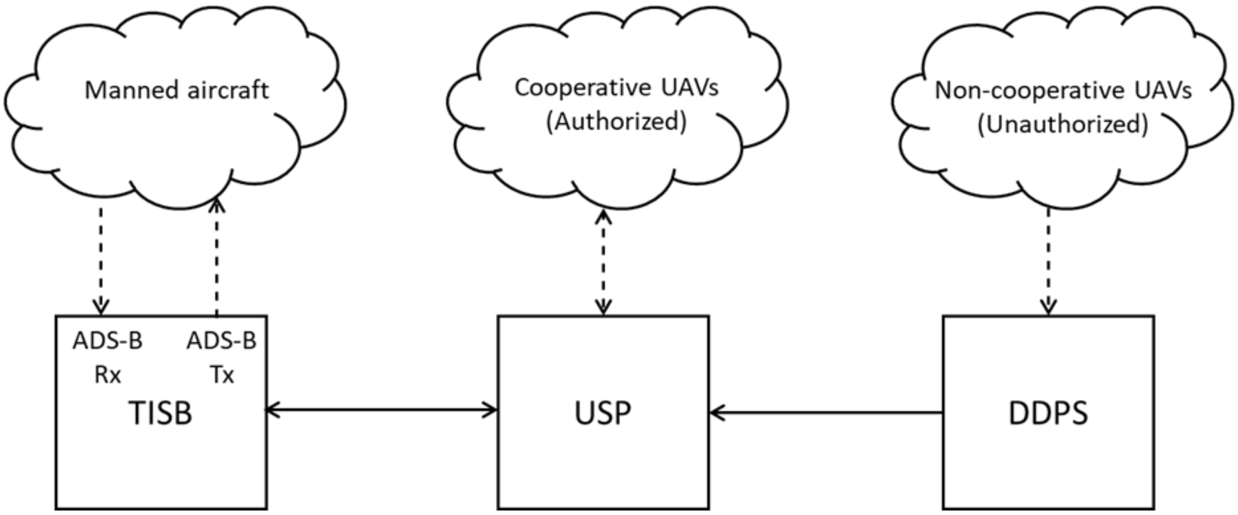

Figure 23: Architecture for UAVs to safely co-exist with manned aircraft in a shared airspace

From the manned aircraft's perspective, the pilot will obtain positional information on all types of UAVs in the aircraft's cockpit through the aircraft's ADS-B receiver. As depicted in the above figure, the information originates either from DDPS or USP. In either case, the USP sends positional information to TISB, which will broadcast (low-power ADS-B transmitter) the location of the UAV to the aircraft.

From the UAV's perspective, it will obtain positional information on manned aircraft from its USP. The information originates from the manned aircraft broadcasting its location using its built-in ADS-B transponder. The location of the manned aircraft will be obtained by the ground-based ADS-B receiver of TISB, which sends it further to the USP.

To summarize, the proposed architecture remedies both the issue with non-cooperative UAV and the lack of information sharing between manned aircraft and cooperative/non-cooperative unmanned aircraft. To “see" and "be seen" is the key enabler for UAVs to safely co-exist with manned aircraft and enable BVLOS beyond line-of-sight operations.

8.4 HAPS networking

Terrestrial networks, by nature, are not able to provide full geographic coverage in an economical way, due to natural terrain obstructions. Also, for spectrum usage, higher frequencies are not very well suited for rural settings as site to site distance is rather large, following legacy deployments on lower frequency bands. To use higher frequencies for mobile broadband services at rural sites would bring coverage only to limited range from the site, while if provided from low stratosphere using HAPS, the higher frequencies can still be meaningfully utilized to provide service for large areas, thanks to much higher probability of Line of Sight propagation.

From MNO perspective, a HAPS has potential to provide virtually 100% geographic coverage and bring capacity to areas that are underserved by terrestrial network, with seamless integration to existing terrestrial network.

LEO constellations also aim to provide Direct to Device (D2D) services, however with coverage limited to outdoor scenarios. Advantage of HAPS for D2D services is that it can also provide indoor coverage, thanks to lower physical distance.

Services provided via HAPS also provide a resilient overlay for terrestrial network. With HAPS, network capacity can be provided flexibly and on short notice where needed without involving physical site roll-out actions as is the case with terrestrial networks. For areas out of reach of Ground Station, a satellite link can be exploited for feeder link.
With HAPS, compared to satellite, we have the possibility to upgrade the physical payload in a flexible manner.

HAPS can complement 3D network by catering for following use cases:

- Extending terrestrial coverage to white spot areas, for 3GPP based services.
- Disaster recovery support by overlaying affected (damaged) network.
- Support of new service types, such as airspace management traffic (including non-3GPP).
- Wireless broadband in areas where fiber roll out is not feasible.
- Temporary coverage for events, such as outdoor sporting events in rural settings.
- Providing connectivity to other 3D nodes.

HAPS can also serve other use cases, such as geo-observation, photogrammetry etc.

Free Space Optics (FSO) is a technology that offers very high capacity over large distances. The Achilles‘ heel of the technology is its dependency on clear sky weather. Weather effects such as rain or fog impair the link. However, for operation above weather, we are free of these constraints and can provide high capacity links among HAPS and satellite nodes.

HAPS with backhaul using satellite services have the following advantages:

- Better link margin / availability as the HAPS platform operates above weather systems which are the main contributor of atmospheric losses causing service degradation.

- Mobile high throughput services via satellite require considerable terminal complexity in terms of size, weight, power (SWaP) and cost. HAPS can act as a relay for nearby aerial and terrestrial 3D nodes on large area to provide connectivity via satellite or Ground Station.

For additional capacity, new parts of spectrum (Ka and above) must be identified.

To validate these novel concepts, we can utilize existing stratospheric platform with Remotely Piloted Aircraft System (RPAS) capabilities, allowing flexible integration of various payload types. Currently available platform provides high (SWaP) capability, however it is mainly suited for experimental use rather than commercial deployment. Such practical flight trials are foreseen to take place in Germany, in close coordination with other involved partners and their experiments.

Practical experiments are expected to include study of various 3D architectures, such as:

- HAPS to Ground
- HAPS to low altitude UAV
- HAPS to Satellite

Such topologies would be tested in an isolated test network, providing full end to end network services. New frequency bands in range of 7 to 12 GHz, discussed as candidates for 6G, are also a subject for study. Such frequencies are not attractive for terrestrial deployment in rural and deep rural environment, however they are promising candidates for HAPS and NTN in general.

9 Digital Airspace & NTN use cases, scenarios and regulations impact on sustainability

The information and communications technologies (ICTs) industry plays a vital role for combating the world's climate change and sustainability challenges. The United Nation's introduction of its sustainable development goals (SDGs), which include a framework of the 17 areas that need to be addressed and that works as a guideline for reaching a sustainable world [13].

The ICTs are the backbone of today's digital economy and have enormous potential to accelerate the progress for reaching the SDGs and improve people's lives by enabling and providing worldwide mobile connectivity and global coverage [14]. ICT is crucial for achieving all the 17 SDG goals (displayed in the Figure 24 below) and should be considered as a catalyst for accelerating the three pillars of sustainable development: economic growth, social inclusion, and environmental sustainability.

Figure 24: The United Nation's 17 Sustainable Development Goals.

With more than half of the world's population already living in urban environments, and with the estimation that about 70% of the world's population will be living in urban areas by 2050, ICTs will be essential in offering innovative ways to managing cities more effectively through, for instance, smart buildings, intelligent transport systems, smart water and waste management, and effective energy consumption etc.

The establishment of UAM will also play a vital role in the evolution of urban sustainability. Satellite-based communication systems do not only provide data for monitoring of weather, climate data etc. but can ultimately also complement the terrestrial communication networks by providing additional connectivity for rural and sparsely populated areas.

The 2030 Agenda for Sustainable Development highlights that the continuous development and the spread of information and communication technology has a great potential to bridge the digital divide [15].

In Europe, the SESAR ATM Masterplan predicts a growth of air traffic in the future [46]. But while the benefits of a continued growth in air traffic for European citizens are clear in terms of mobility, connectivity, and availability of new services (e.g., services that will be enabled by drones/UAV etc.), this growth also brings concerns about climate impacts. These concerns are prompting the aviation industry to accelerate its efforts to address air travel environmental sustainability.

The EU has a plan to cut greenhouse gas by at least 55% by 2030 and reach its carbon neutral goal by 2050 [16]. In support of this goal, the SESAR project has prioritized solutions that will gradually contribute to the elimination of environmental inefficiencies caused by the aviation infrastructure. This will be done by ensuring that it provides solutions that will exploit the potential offered by next generation aerial vehicles and aircrafts. The main ambition of the SESAR project is working towards the digitalization of ATM and to support electrification of aerial vehicles, where the overall goal is to strive for a more climate neutral aviation industry.

The challenges of global climate change and the need to reduce our carbon footprint makes it critical that the next generation 6G networks employ the most energy efficient available technologies, that will reduce the dependency on non-renewable sources and use solely renewable energy sources.

In addition to energy consumption and emissions, the ICT sector's overall environmental impact must also be considered, including the handling of water consumption, raw material sourcing, and waste handling etc. 6G is considered by many to be the sustainable "Green G" [17]. Use cases that will emerge related to 6G and also to 6G-SKY, including all key actors in the entire value chains, will need to embrace a strong focus on sustainability and work actively towards reducing any climate change impacts.

In terms of future spectrum strategy and regulations, these should be seen as an enabler for technology with an essential focus on sustainability and will also work towards spectrum being used as efficiently as possible. The ITU has stated that it strongly supports and encourages the efforts of countries to leverage technology to accelerate progress towards the SDGs and is also developing a framework for assessing the impact – both positive and negative – of digital technologies on the climate" [18].

The 6G sustainability study in [19] has shown for a city scenario that HAPS can reduce grid energy of a mobile network by 10% to 50% by switching off terrestrial base stations. Large part of rural terrestrial sites are deployed for providing coverage and not for capacity need. HAPS can replace such towers in wide sparsely populated areas. Furthermore, novel hydrogen based power solutions are promising carbon free network operation.

10 Conclusion

Holistic adaptive combined ASN networks for 6G is needed to meet the expected massive growth of aerial platforms, which will require automization and digitalization of airspace systems. On top of this, sustainability will drive new propulsion methods and digitalization will drive the growth towards connected aerial platforms.

Our regulatory studies show that it is important to keep up a holistic mindset as aerial platforms will interact with each other. This will drive issues in regulations and spectrum.

The use case segments for combined ASN networks are evolving and have different maturity. Use case segments like commercial airplane traffic and satellites are more established, while other use case segments is in its infancy e.g. Urban Air Mobility.

Over time, more advanced requirements on communication will appear, which will then require that wireless systems can cater to evolved 3D solutions. 6G-SKY has an extensive set of use cases both in studies as well in demos. They all contribute to show holistic network requirements and the need for holistic network support. If societies will welcome combined ASN networks, the sky will not be the limit, space is included.

11 References

11.1 Papers

Papers List:

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11.2 Figures

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Annexes: none