6G for Connected Sky
"6G-SKY"

Work Package 1

Holistic Adaptive Combined Airspace and NTN networks Architecture for 6G

Task 1.3: Holistic adaptive Airspace and NTN architectures with multi-technology communication links for 6G
Task 1.4: Joint sensing, communication and computation in 3D
Task 1.5: Safe and explainable AI for adaptive and robust communications

Deliverable D1.2

First draft of combined ASN networks architectures for low altitude platforms for UAM and rural areas

6G-SKY Project
30 April 2023

<for full publication>

Abstract

This D1.2 intends to provide an initial draft of the 6G-SKY architecture focusing on low-altitude platforms for urban air mobility and rural areas. This report outlines architectural principles to be followed for the combined airspace and non-terrestrial network architecture including high-altitude platforms and satellites with careful consideration of network functions and use case requirements. Requirements and challenges posed by the architecture, network management and control in the multi-layered 3D network are discussed. The architectural options for different scenarios are introduced with a mapping study of the current technical solutions.

Participants in WP 1: EAB, KTH, SAS, PTS, AITIA, Skysense, Airbus, Motius, Ericsson Hungary, Lakeside Labs, Red Bernard, Twins, LCA, DT, Fraunhofer

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

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D1.2: First draft of combined ASN networks architectures for low altitude platforms for UAM and rural areas

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[6G-SKY]

[Document title]: D1.2 First draft of combined ASN networks architectures for low altitude platforms for UAM and rural areas

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Document History

Version	Date	Author(s)/Reviewer	Comment
A	2023-04-30	6G-SKY partners	Mustafa Özger, KTH: Driver of D1.2

Executive Summary

This deliverable aims to provide the reader with the initial design considerations of architectures for the combined airspace and NTN networks (combined ASN networks) with a focus on low altitude aerial platforms including airplanes as users.

This project report first discusses the primary principles for the design of combined ASN network architectures. These principles for the holistic adaptive 6G-SKY network architecture require new functional views to assure three-dimensional (3D) service requirements via network functions such as 3D end-to-end (E2E) and domain-oriented network orchestration and slicing. Other dimensions shaping the 6G-SKY network architecture are the EU aviation strategy with EU Single European Sky (SES) and Single European Sky ATM Research (SESAR) initiatives and requirements from urban air mobility and advanced air mobility. The report discusses design aspects of the ASN architecture to enable efficient network management and control of the multi-layered architecture. This deliverable investigates cloud-native architecture options such as variants of cloud radio access networks and open radio access networks (O-RAN and potential other open radio networks) to satisfy the requirements of ASNs.

Joint sensing and communication, and safe and explainable AI are the intended capabilities that the 6G-SKY network architecture supports. To this end, this report first discusses sensing scenarios in the 6G-SKY and possible combinations for sensing. Based on the 3GPP discussions, this report suggests a set of network functions to support joint sensing, communication, and computation. Furthermore, the application of explainable AI in 3D networks is discussed to provide robust communication to avoid disconnections, take corrective actions, and predict and avoid failures.

An analysis of communication requirements for different aerial platforms at different altitudes is performed considering multi-technology communication links. Based on this analysis, the report maps potential technical solutions for the selected aerial platforms. This report also studies the connectivity in rural areas via UAV swarms focusing on their coordination and UAV hardware.

The 6G-SKY network architecture will contribute to the sustainability goals via its contribution to the realization of smart transportation and digital airspace. It will lead to safer and more secure air traffic management and open up new business opportunities toward economical sustainability.

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List of acronyms in alphabetical order.

Acronym	Description
Access and Mobility Function	AMF
Advanced Air Mobility	AAM
Aeronautics Research Mission Directorate	ARMD
Air Navigation Service Providers	ANSPs
Air-to-Air communications	A2AC
Artificial Intelligence	AI
Authentication Server Function	AuSF
Baseband Unit	BBU
Central Unit - control plane	CU-CP
Central Unit - user plane	CU-UP
Cloud-RAN	C-RAN
Combined airspace and NTN networks	combined ASN networks
Common Public Radio Interface	CPRI
Constant bit rate	CBR
Digital unit	DU
Direct air-to-ground communications	DA2GC
Distributed units	DUs
Electric Vertical Take-Off and Landing	eVTOL
End-to-end	E2E
Global Navigation Satellite Systems	GNSS
HAPS as IMT base stations	HIBS
High altitude platforms	HAPS
Information and communications technologies	ICTs
International Civil Aviation Organization	ICAO
Internet of Things	IoT
Network Exposure Function	NEF
Non-terrestrial networks	NTNs
Open Base Station Architecture Initiative	OBSAI
Open radio access networks	O-RAN
Quality of service	QoS
Radio access networks	RANs
Radio Intelligent Controller	RIC
Radio units	RUs
Remote Radio Head	RRH

Required Communication Performance	RCP
Road Side Unit	RSU
Satellite communications	SC
Sensing Controller	SeC
Sensing Management Function	SeMF
Sensing Schedulers	SeSch
Sensing Task List	SeTL
Simultaneous localization and mapping	SLAM
Single European Sky ATM Research	SESAR
Single European Sky	SES
Software-defined networks	SDNs
Sustainable development goals	SDGs
Terrestrial networks	TNs
Three-dimensional	3D
Time-wavelength-division multiplexed passive optical network	TWDM-PON
Transaction expiration time	ET
Transaction time	TT
Two-dimensional	2D
UAS Traffic Management	UTM
Unmanned aerial vehicles	UAVs
Unmanned airborne system	UAS
Urban air mobility	UAM
Urban air mobility	UAM
User equipments	UEs
User Plane Function	UPF
Virtualized base station	V-BS
Working groups	WGs

1 Introduction

The 6G-SKY project aims at integrating terrestrial networks (TNs) and non-terrestrial networks (NTNs) through a holistic architecture utilizing multiple communication technologies such as direct air-to-ground communications (DA2GC), air-to-air communications (A2AC), satellite communications, high altitude platforms (HAPS), and HAPS as IMT base stations (HIBS). Targeted connectivity scenarios in the 6G-SKY project span from coverage or capacity extension via NTNs to covering aerial users such as unmanned aerial vehicles (UAVs), flying taxis and airplanes. These scenarios cover diverse use cases such as urban air mobility (UAM) and the Internet of Things (IoT) in rural areas.

1.1 Objective of the document

The objective of this document is to lay foundations of the holistic architecture for combined Airspace and NTN networks, especially focusing on the connectivity of low-altitude platforms in urban and rural areas. To this end, this deliverable explains the requirement and architectural principles of the holistic architecture with functional views, which covers both airspace and NTN (satellites). The required functions from the architecture such as joint sensing and communication and trustworthy AI are discussed for low-altitude platforms. One of the main contributions of this deliverable is to analyze the communication cases to provide connectivity service to aerial users. This deliverable also shows architectures with multi-technology communication links for the specified use cases with a comparison study of different options for the architectures and mapped technical solutions.

This deliverable has two main objectives for the project execution:

- Providing network architecture inputs to other technical work packages,
- Providing initial draft for the holistic architecture.

1.2 Structure of the document

This deliverable is organized as follows:

- Section 2 discusses key aspects of combined ASN architectures. In this section, 6G-SKY views on the definition of holistic networks, architecture principles followed to design the 6G-SKY network architecture, the required architectural functions, challenges and requirements are discussed.
- Section 3 provides information regarding the capabilities this 6G-SKY architecture possesses. More specifically, joint sensing, communication and computation and trustworthy AI functions are discussed considering 3D holistic networks.
- Section 4 discusses holistic and adaptive architectures utilizing multi-technology communication links. Different segments in airspace are investigated in this deliverable to capture UAM and rural areas.
- Section 5 reviews the sustainability aspects of this deliverable.
- Section 6 concludes this deliverable.

2 Architectural Principles on Combined ASN networks architectures

2.1 Definition of holistic networks for aerial platforms

The definition of holistic networks for aerial platforms is influenced by several factors and may differ in different contexts. Hence, the 6G-SKY project has evaluated naming terminologies for holistic networks covering all aerial and space-borne 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, academic literature and general acceptance of the proposed terminology.

In conclusion, the 6G-SKY has chosen the following naming terminology for holistic networks covering all aerial and space-borne platforms at all altitude levels: Combined airspace and NTN networks, abbreviated *combined ASN networks*.

Combined ASN networks are integrated with terrestrial networks. The chosen naming terminology is judged to have the greatest chance to win acceptance among different stakeholders. For combined ASN networks, Airspace is considered to encompass all aerial platforms that can fly, including HAPS/HIBS. NTN is considered to include only space-borne platforms such as satellites.

We elaborate on the other naming terminologies with their shortcomings below.

2.1.1 NTN in its wider sense

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

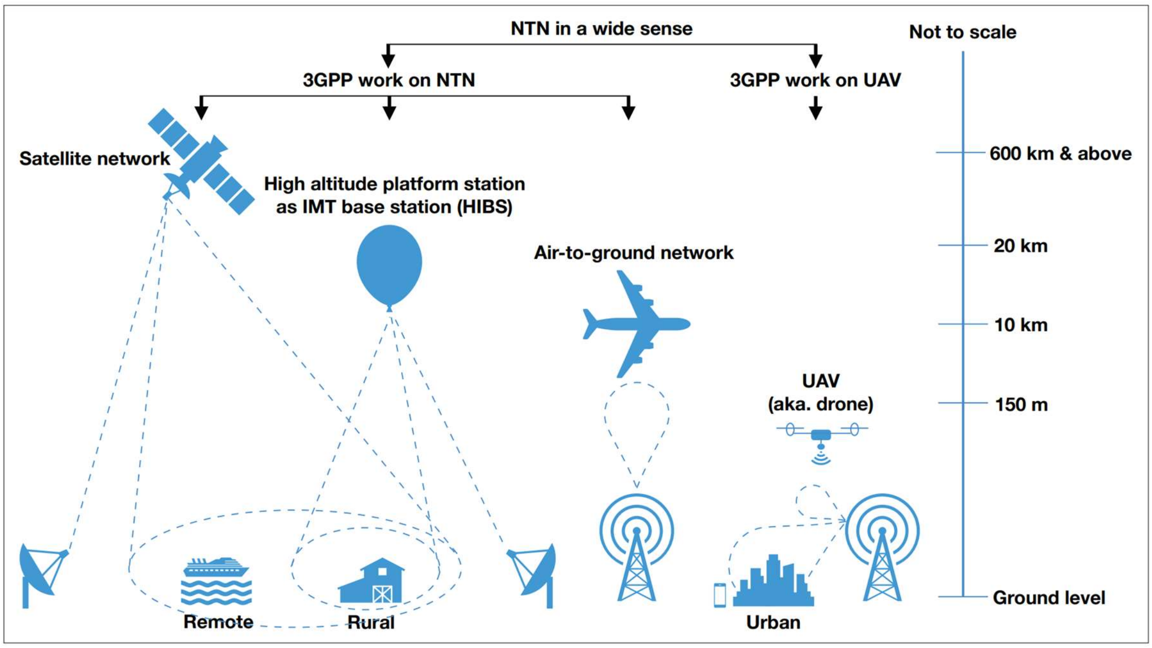

Figure 1: Different types of non-terrestrial networks [1].

The attempt here has been to take the term NTN, which many refer to satellites, and broaden its meaning to cover all aerial platforms at all altitude levels. It is very hard to get acceptance for this widening, and it also creates confusion among stakeholders. In many cases, it creates a need to define NTN on every occasion whether it is viewed as a term for satellites or used in its wider sense.

When the 6G-SKY project was established, NTN was viewed in its wider sense. The 6G-SKY project has now chosen to refer NTN to satellites. This resonates well with 3GPP which uses NTN for satellites in 3GPP TS 38.300, with an implicit support for HAPS.

2.1.2 Airspace

Airspace is a term that is used widely within SESAR [2]. The issue with airspace is that it may exclude satellites [3], see below:

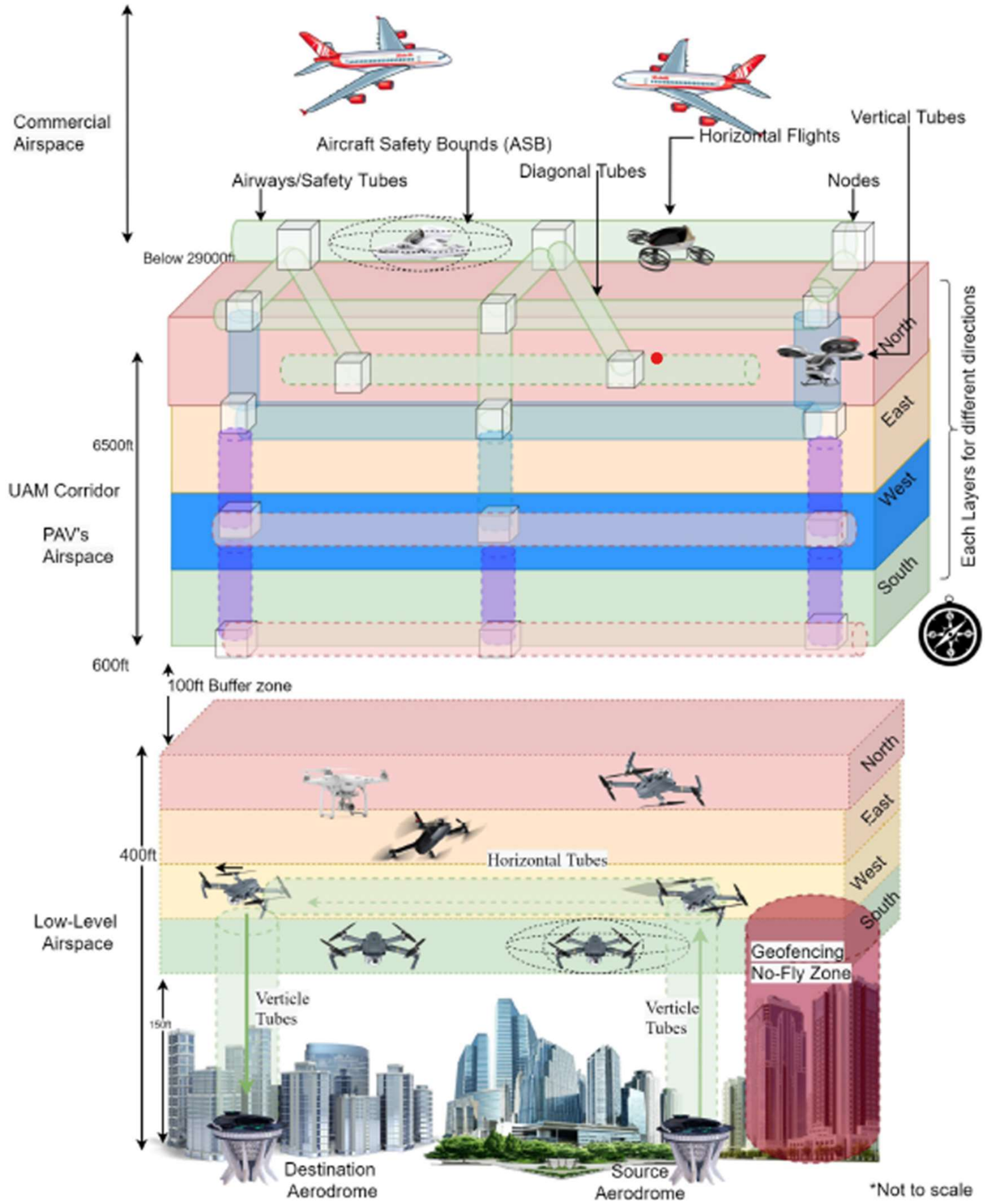

Figure 2: Airspace networks [3].

2.1.3 Ground Air Space networks

Ground air space networks were introduced by [4], see figure below:

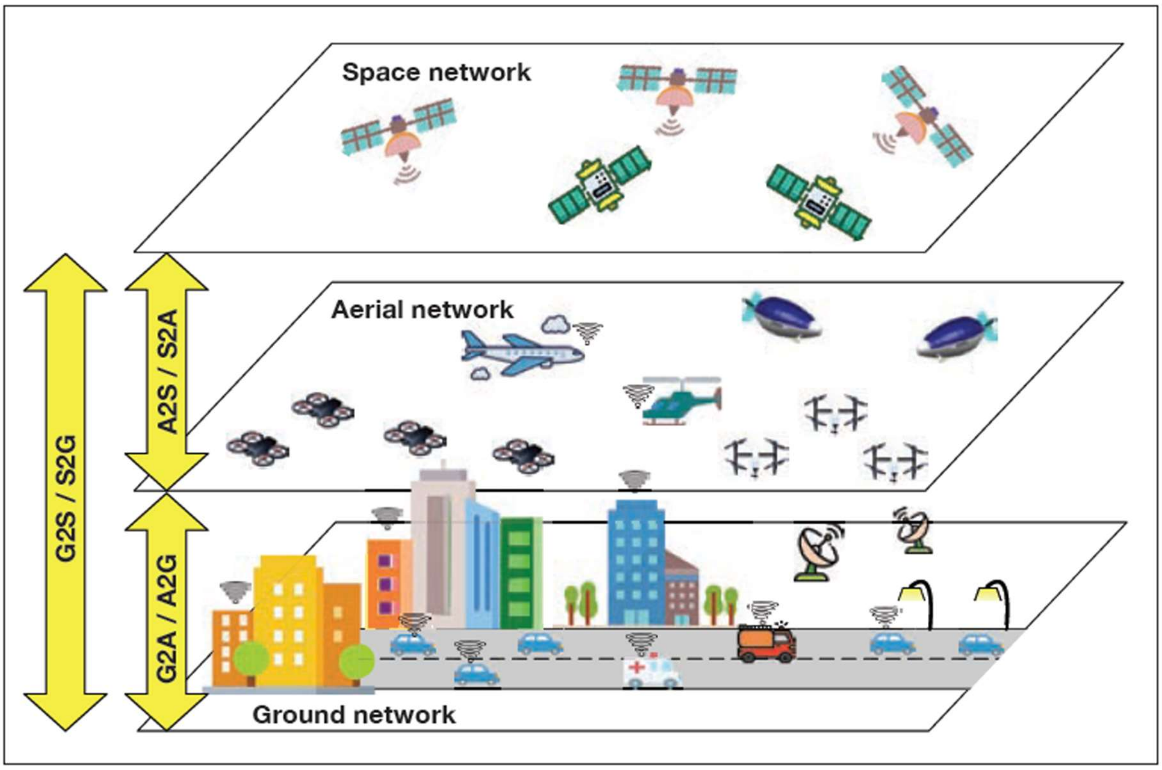

Figure 3: Ground Air Space networks 4

This model creates some confusion with terms e.g., used within 3GPP, where ground networks are referred to as terrestrial networks. Furthermore, this terminology mainly discards connectivity of aerial users.

2.1.4 ITU regulations

ITU 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 involving the use of one or more space stations or the use of one or more reflecting satellites or other objects in space

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

2.1.5 Conclusion

Combined ASN networks have some disadvantages. It would perhaps have been more practical to have a single name for holistic networks. However, whichever name is introduced, it must also be viewed from the perspective that it can get general acceptance among stakeholders.

Combined ASN networks work well for most stakeholders. It resonates well with the usage of Airspace in SESAR, NTN in 3GPP, and also for research papers that use the terms airspace and NTN. There is also a benefit that combined ASN networks can work well with industry players.

2.2 Summary of Architectural Principles supporting the 6G-SKY Holistic Adaptive Combined ASN Networks Architecture for 6G

Below follows a summary of architectural principles supporting the 6G-SKY holistic adaptive combined ASN networks architecture for 6G:

- It is important that the 6G-SKY Holistic Adaptive combined ASN networks architecture and the integrated TN Architecture cover all functional levels of the communication system.
- The combined ASN networks will drive 3D requirements into functions and architecture.
- The combined digital airspace & NTN networks will increase the number of communication use cases, which impacts not only data and control planes but also drives alternatives for execution either NTN, TN or with an integrated approach of NTN and TN.
- The radio interface must be flexible, adaptable and fast to adjust to radio conditions and capacity needs from applications emerging from combined ASN networks.
- Signaling must be designed to be able to support a massive amount of UEs and/or relays in 3D space for Combined ASN networks and TN.
- Mobility management must be able to handle massively scaled radio access networks (RANs) & user equipments (UEs) in 3D space for Combined ASN networks and TN.
- Session Management must be able to handle more diverse requirements on session handling & optimizations of service continuity for Combined ASN networks and TN.
- Application management must be designed to support diverse needs and the interaction with cloud and caching systems.
- AI shall be embedded in the system and be able to balance central and/or distributed execution.
- The wireless system must be able to integrate more diverse systems demands and solutions as well as interact with the digitized society.
- The 6G-SKY Holistic Adaptive Combined ASN networks and TN Architecture must be able to cater for 6G research challenges: sustainability, Internet of senses, extreme experiences, extreme performance, connecting intelligence, networks of networks, global service coverage, and trustworthiness.
- The 6G-SKY Holistic Adaptive combined ASN networks and TN Architecture must be able to support the target architecture envisioned by SESAR.
- It is important that the 6G Holistic Adaptive combined ASN networks and TN Architecture can inter-work with combined ASN networks solutions and TN from 4G, 5G, and 5G advanced as well towards other networks.

2.3 The 6G-SKY Holistic Adaptive Digital airspace and combined ASN networks - functional view

Architectures can be shown in different ways. Below is the way the 6G-SKY has presented the holistic combined ASN networks and TN architecture. It has a functional approach and stresses the need for combined ASN networks and TN integration as well as highlighting the need for looking at functions from a 3D perspective. The architecture allows for a life cycle handling of service executions and allows interaction between different layers. It is very important to stress that executing services to aerial platforms require the involvement of all layers and not only "links". These functions, which are illustrated in Figure 4, are briefly explained in the following sub-chapters.

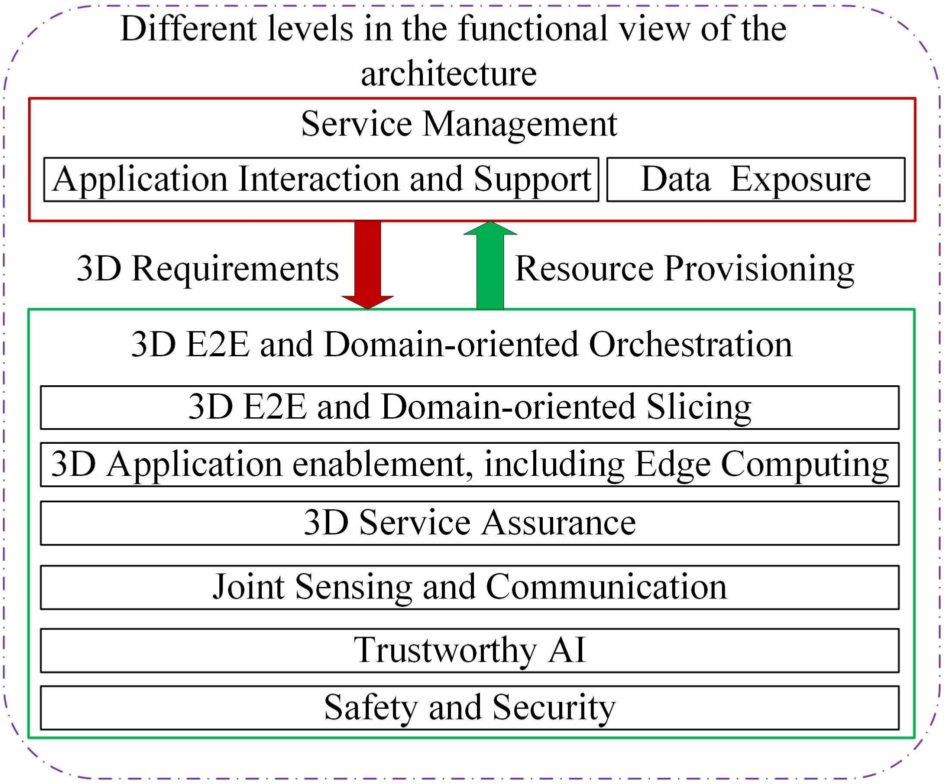

Figure 4: Combined ASN networks and TN architecture - functional view.

2.3.1 Service management

Service Management covers the process for handling of activation, changing and closing a service from a service life cycle perspective. It represents a borderline towards external service activation based on customer requests but also an internal operator borderline for service activation towards the network. It means the service management will interact with domain-oriented management systems to establish, change and close services from a life cycle perspective.

2.3.2 Application Function Interaction and Support

The wireless system has APIs towards the application layer supporting the interaction with the wireless systems activities related to service management and supporting requests from the applications for their execution. It might be for certain large applications that distributed application software is developed for the distributed execution of the application between the application data center and the wireless system.

2.3.3 Data exposure

Data can be exposed. The data can be processed at system levels, applied with AI and aggregates can be sent to the receiver of the exposed data. Exposure can support internal wireless data usage

needs but also external exposure. The data exposure layer can potentially also interwork with the application function interaction and support layer.
The data exposure is typically handled with APIs that can be standardized or customized depending on the receiver. The current 5G architecture has started to implement support for exposure, e.g. Network Exposure Function (NEF) [5].

2.3.4 3D E2E and domain oriented orchestration

Combined ASN networks will drive 3D requirements, including dynamic network nodes, into orchestration. E2E aspects must be able to be implemented on domain level. The orchestration is typically layered where the network resources are first secured on E2E perspective and in the next step broken down per network domain.

2.3.5 3D E2E and domain oriented slicing

Combined ASN networks will drive 3D requirements into slicing concepts from an E2E perspective. E2E aspects must be able to be implemented on the network domain level.

2.3.6 Enabling 3D Application including edge computing

Applications can be executed by different architectures that can be dynamically adapted by the system; centralized execution or distributed execution, in many cases enabled by cloud execution environments. The 3D application enabling layer must be able to interact with other layers depending on needs. Slicing KPIs must be able to be fulfilled and orchestration must be synchronized to support chosen execution options.

2.3.7 3D service assurance

Combined ASN networks will drive 3D requirements into service assurance. Service assurance needs to be supported both on the overall management level and also at the domain level. Service assurance can be supported by policies on how different services and subscriptions should be handled. At a certain stage, the user will issue a close down of the service. Then, the 3D service assurance layer must be able to interact with the service management layer to close down the service.

2.3.8 Joint sensing and communication

Not only the networks but also each UE device can be considered as a sensor. Inherent possibilities of joint communication and sensing technologies, beam-sweeping, beam maintenance, and ultra-wide band scanning technologies available to precisely locate a given UE, especially in the LOS environment are envisaged to be typical for aerial users in the future.

2.3.9 Trustworthy AI

Many industries including aviation consider AI in critical, potentially safety-related operational contexts. AI can act on different layers such as physical and network layers in 6G. On one hand, aviation can potentially profit from AI optimized 6G networks to achieve performance parameters such as transmission reliability and data rate. On the other hand, implications for 6G services by AI-based networks that are used for critical aviation tasks need to be risk assessed.

2.3.10 Safety and security

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 for 6G.

2.3.11 Integrated combined ASN networks and TN infrastructure

There are many architectural options for how the combined ASN and TN components can interact with each other. The infrastructure consists of combined ASN aerial and space platforms (e.g., satellites, HAPS/HIBS, airplanes, drones/UAVs, air taxis, and 3D core) with terrestrial radio access networks supported by terrestrial backbone, core, transport and data networks. It is even possible to have combined ASN networks dedicated to 3D Core solutions supporting standalone or integrated core solutions with the TN.

2.4 Architectural Requirements and Challenges for Low Altitude Platforms for UAM and Rural Areas

2.4.1 6G-SKY architecture alignment with the EU aviation strategy and with the EU SES & SESAR Initiatives

EU has the intention to create the Digital European Airspace by 2040. The background is an analysis that aerial platforms will grow in type and use. The growth of aerial platforms will require automation of the airspace, which in turn will drive the digitalization of the European airspace. The vision is described in the European ATM master plan as follows [2]:

"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 Air Navigation Service Providers (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 organisation 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 [6], acknowledges SES and SESAR [2] 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 an 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:

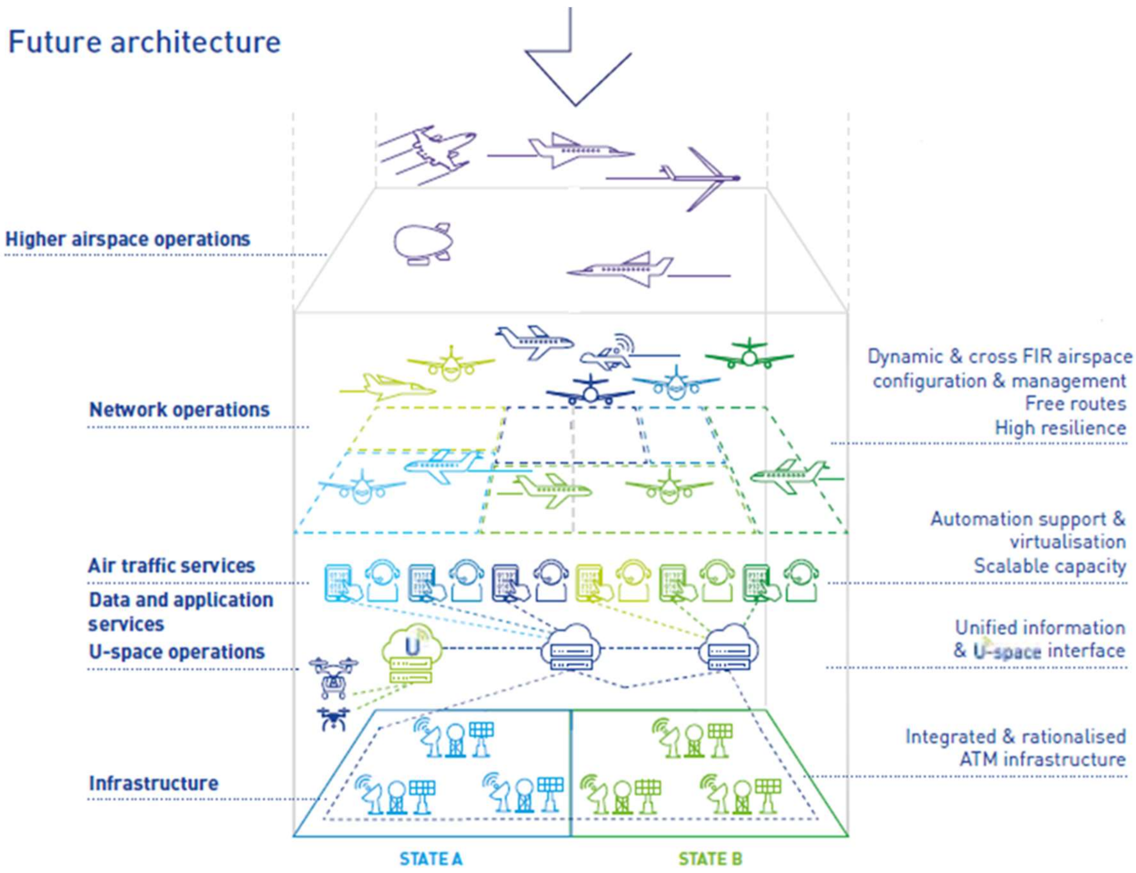

Figure 55: SESAR Target architecture [2].

The 6G-SKY approach with the holistic combined ASN networks is well aligned with the EU vision for a Digital European airspace and the holistic architecture envisioned by SESAR.

SESAR has also defined a road map 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 [7]. 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 airspace' means an unmanned airborne system (UAS) geographical zone designated by Member States, where UAS operations are only allowed to take place with the support of U-space services provided by a U-space service provider. U-space relies on a high level of autonomy and connectivity in a combination with 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 [7], 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 6 below), to support the EU aviation strategy and regulatory framework on drones/UAVs. Each new phase will introduce a new set of services while including an upgraded version of the services already existing in the previous phase.

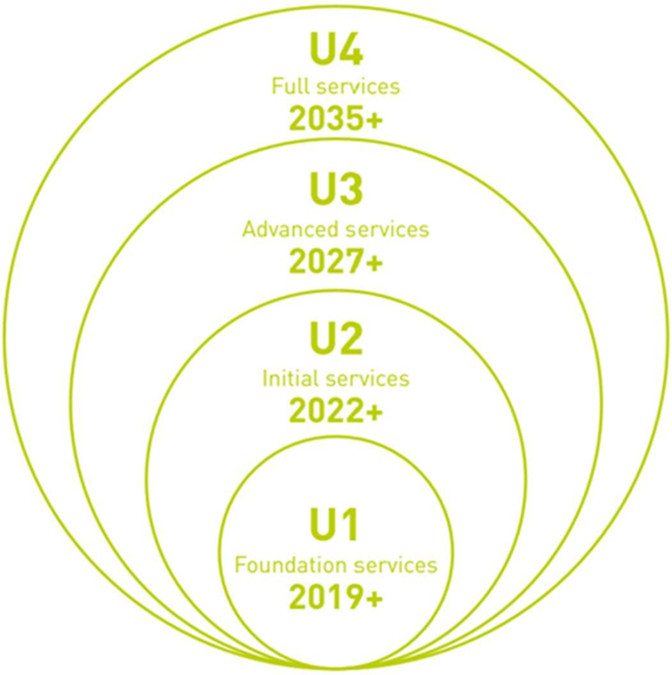

Figure 6 U-Space roadmap according to the European ATM master plan [7].

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 consist of a set of initial services designed to support the safe management of BVLOS operations. U2 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.

2.4.2 NASA Advanced Air Mobility and UAM

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 [1]. 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 [55].

These WGs contribute to the Organizational Framework, which is divided into five main pillars, which are listed as follows [1]:

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.

For safe operations in AAM systems, communication between the system components is very important. Collision avoidance is one of the scenarios where the communication plays a key role. AAM envisions to use vehicle to vehicle (V2V) links for the collision avoidance [8]. V2V links may also be utilized for separation provision, traffic synchronization and airspace organization.

Urban air mobility (UAM) is an emerging concept defining procedures and rules with technology enablers to realize the mobility of passenger and cargo in the air [9]. UAM can be considered as a limited vision being part of the AAM with a broader concept including regional and rural mobility. As the industry pushes their technologies with aerospace suppliers to be certified for urban air mobility and the current air traffic management system is incapable of handling such dense traffic in the air, this mandates a new management system of airspace especially in urban areas. UAS Traffic

Management (UTM) has emerged for the operations of aerial vehicles in low-altitude airspace [10], which is a service-oriented architecture to be used for UAM operations. Hence, UAM requires coordination and interaction of various system components such as air traffic management, infrastructure and ground-based transport systems with a consideration of public safety and acceptance [11].

To realize these concepts for aerial vehicle operations in low altitudes, reference [2] has shown a mismatch toward technical performance measures between the aviation community, through the notion of Required Communication Performance (RCP), and the communications community. It is important to bridge this gap, especially since a new set of aerial vehicle types emerges:

- UAVs/Drones
- Electrical vertical take-off and landing (eVTOL) vehicles
- High-altitude platforms (HAPS) systems

The International Civil Aviation Organization (ICAO) introduced RCP based on the following parameters:

- Transaction time (TT): the time needed for a transaction to be completed.
- Transaction expiration time (ET): the maximum time for the completion of the transaction after which the initiator is required to revert to an alternative procedure.
- Availability (A): the required probability that a transaction can be initiated when needed.
- Continuity (C): the required probability that a transaction will be completed within the ET, given that the service was available at the start of the transaction.
- Integrity (I): the required probability that a transaction is completed without undetected errors.

Especially for availability, it should be noted that it mismatches with common definitions in the communication community.

RCP is selected based on vehicle and network service capabilities. The reference proposes this set of RCPs:

RCP type	ET	C	A	I	Origin
RCP 400	400s	0.99	0.999	10^{-5}	ICAO
RCP 240	240s	0.99	0.9995	10^{-5}	ICAO
RCP 120	120s	0.99	0.9995	10^{-5}	ICAO
RCP 60	60s	0.99	0.9995	10^{-5}	ICAO
RCP 10	10s	0.995	0.99998	10^{-5}	ICAO
FAO	0.2s	0.995	0.995	10^{-5}	Own estimate
RPO	0.1s	0.99999	0.9999	10^{-5}	Own estimate
RCO	40s	0.99999	0.9995	10^{-5}	Based on NASA

FAO: Fully Autonomous Operation
RPO: Remote Piloting Operation
RCO: Reduced Crew Operation

Table 11: Required communication Performance for aerial vehicle operations

2.5 Network Management and Control

In spite of the wide level of heterogeneity of current communication network services, the communication needs of various types of users being either humans, machines or even larger infrastructures, current 5G networks mainly considering a flat, two-dimensional (2D) type and mostly static network architecture. These flat networks focus on base station based serving of terrestrial terminals in mobile networks or satellite-based communication for some selected groups including aerial users like airplanes as well as terrestrial users on the ground like smart-phones and stationary terminals.

An emerging challenge is to complement existing terrestrial communication systems forming a flexible 6G hybrid architecture integrating terrestrial, dynamic HAPS and satellite layers with an additional aerial layer with users such as UAVs and airplanes. As in terrestrial communication, the service requirements are diverse in aerial applications and dynamically changing such that a 3D integrated network design should be able to adapt its topology and resources according to the needs of both terrestrial and aerial users.

Network management and control in 3D networks is a very demanding task due to challenges posed by 3D mobility, interference, handover and limitations of aerial vehicles such as size, weight, power and computation. A common way is to integrate UAVs into cellular networks as UEs, which are called cellular-connected UAVs via DA2GC [12].

Interference is the biggest obstacle to this integration. Uplink communication from UAVs to BSs may incur significant interference to the terrestrial UEs. For downlink communication, UAVs may receive interference from unintended BSs. Due to their 3D mobility, UAVs are in the LOS condition with several BSs, which makes the BS association problem challenging, as already identified in 3GPP in the study report TR 36.777 [12].

The speed of UAVs and a large set of LOS BS also cause an excessive number of handovers [13]. For cellular-connected UAVs, handover and radio resource management in serving UAVs coexisting with terrestrial users becomes one of the key research problems for cellular-connected UAVs and integrating UAVs as UEs into the terrestrial networks. To manage such integration, key performance indicators are interference to/from UAVs and BSs, delay, amount of allocated radio resources and rate of handovers.

On the other hand, DA2GC is not the only option for UAV connectivity. Other connectivity options for the UAVs or flying vehicles are HAPs and HIBS, and satellites. They also suffer from the coexistence challenges such as interference and allocation of radio resources at different levels, as described in [14]. Hence, network management and control become a major task in the holistic 6G-SKY architecture.

The main focus of radio resource management in such a future 3D environment is to control and harmonize the network side domain towards the optimal resource allocation and load balancing between the connection domains including the cost, QoS demands as well as energy efficiency aspects of connections. Moreover, such multi-domain networks might be operated by different operators, so multiple operator policies have to be mapped to the service control logic. As the network complexity increases, when terrestrial and aerial users are served by a multi-layer network architecture, the optimization of the radio resource management by AI is advantageous.

In the multi-layer 3D network architecture, the users might be connected to multiple serving layers (e.g., consider dual or multi-connectivity to traditional terrestrial networks and satellites). Hence, the mobility handling (handover) depends not only on their altitude, but a special attention has to be taken on the typically LOS conditions of aerial users and the resulting potential interference between aerial and terrestrial communication links as well as largely overlapping service areas (aka cells in traditional terrestrial communications). Thus, the mobility management greatly relies on the accurate reported or predicted localization information of the UEs and knowledge of the individual link qualities.

Localization should be a 6G service for customers independently from the instantaneous availability of connection domains. Not only the networks, but each UE device can be considered as a sensor. Just consider the inherent possibilities of joint communication and sensing (JCAS) technologies, beam-forming and ultra-wide band scanning technologies available to precisely locate a given UE, especially in LOS environment envisaged to be typical for aerial users in the future, as well.

One of the novel elements in the proposed heterogeneous network architecture is the incorporation of direct device-to-device communication, specifically air-to-air communication (A2AC), into the 6G architecture. The motivation behind it is to extend the network coverage even further in the places where no other means of communication are available for the users. However, relying solely on A2AC links for network coverage and use cases such as drone swarms would be inadequate as it is limited to a single hop of communication. To address this issue, the 6G-SKY project aims to incorporate a managed multi-hop network, commonly referred to as a mesh network, to combine multiple A2A links into a single network. The mesh network should also seamlessly interface with other parts of the heterogeneous network architecture, such as terrestrial, high-altitude platforms, and satellite links, in a way that is transparent to the user equipment, allowing for seamless connectivity and efficient use of resources. The transparency of the overall system considers that only a limited amount of communication agents may possess interfaces to other systems and serve as seamless gateways between the networks.

One of the key use cases that an aerial mesh network will enable is the operation of UAV swarms. The project will focus on developing a heterogeneous network design that incorporates mesh networks to support this scenario. Traditional mesh networks are optimized for maximizing throughput, but for UAV swarms, a different approach is needed to prioritize resilience and low latency for command and control data. This is critical for modern precise distributed swarm control algorithms, which rely on real-time communication between the UAVs. Furthermore, the project focuses on the development of more sophisticated swarming algorithms that will adaptively react to the changing radio environment.

The mesh network design as developed in the 6G-SKY project will not only utilize the multi-hop aspect of the mesh network but also leverage multi-path to transport high-priority data through multiple paths to achieve improved latency and reliability performance. The 6G-SKY project will also investigate network slicing within the mesh network, allowing for different traffic streams to have distinct QoS specifications that can be centrally managed in the control plane. This will enable the network to adapt and optimize the resources for different use cases and traffic types, thus providing a more efficient and reliable network.

Considering different types of links and users, centralized network architectures may have advantages in network management and control to decrease interference and manage 3D mobility more efficiently. The centralized management can incorporate different sources of rewards and regrets with respect to network resources and KPIs to ensure certain performance guarantees [15]. However, such management can be prohibitive due to control signalling, and delay and convergence become a problem as there are numerous flying vehicles with different communication requirements. Hierarchical network management and control is another approach, where decisions such as mobility management are taken at different levels in the network to have a more efficient network management and control [16].

2.6 AI-Native and Cloud-Native Architecture Options

Network virtualization and softwarization enable service-oriented network architectures, which transform the current communication networks into a more versatile platform with a converged network [17]. Network virtualization enables decoupling network functions for service provisioning and network/compute capabilities for data transportation, processing and storage [17]. Network function virtualization realizes network functions as software instances running on the infrastructures enabling virtual networks or network slices [18]. In software-defined networks (SDNs), a centralized network controller with a global view of the network splits the data and control planes.

Cloud-native architecture aims to transform the communication networks being an infrastructure for data transportation to a versatile service platform enabling cloud and edge computing capabilities [17]. Achieving network virtualization and service oriented architecture requires convergence of cloud/edge computing and networking [19]. Such convergence needs a holistic perspective for the end-to-end services especially for the emerging services in the 3D networks. Efficient and flexible management of the network becomes challenging due to large scale, complex and heterogeneous communication-compute-storage systems, where machine learning and data analytics are proposed to overcome these challenges [17]. However, due to heterogeneity of ML methods and 3D multi-layer network architecture, we need a holistic vision to intelligently manage network resources.

AI will be a key enabler of 6G networks. To this end, AI-native network architectures are being proposed by ITU [20], industry and academia. One important concept is to enable zero touch paradigm such that procedures are automated without any human intervention to dynamically arrange the communication and computing resources [21]. With respect to latency and/or computing requirements, the cloud infrastructures may be placed at different locations for 6G services. Another architectural approach is the adoption of cloud technologies. Cloud-RAN (C-RAN) allows the partition of base station elements such as antennas and the digital subsystems such as digital baseband [22]. The two elements in C-RAN are called Baseband Unit (BBU) or cloud, and Remote Radio Head (RRH). The RRHs are placed at the cell to serve the users, and the BBU pool is placed at a remote site to be shared among RRHs. The split of functions between the RF client and the cloud in this type of architecture becomes one of the main research questions [23].

Furthermore, the virtualization of functions in the networks is an active research area in this context. The functionality placed in the RF client and in the cloud can be virtualized; and the interface between the RF client and the cloud connects these functions. A number of radio equipment manufacturers have defined two main specifications for the transport of fronthaul traffic: the Common Public Radio Interface (CPRI) and the Open Base Station Architecture Initiative (OBSAI) [24]. CPRI is a serial line interface transmitting constant bit rate (CBR) data over a dedicated channel. OBSAI uses a packet-based interface where the radio signal is sampled and quantized, and, after encoding, transmitted toward the BBU pool [25].

In addition to C-RAN architectures, a number of variants of it are proposed with respect to the distribution of functions related to the network control, caching and communication [26]. Heterogeneous C-RAN has emerged as a new RAN architecture, which consists of heterogeneous network nodes, i.e., macro BSs with high power capabilities and small BSs or RRHs [27]. Macro BSs implement control plane functions to enhance coverage and control network signaling. On the other hand, small cells enhance the network capacity and satisfy the quality of service. Another type of C-RAN architecture is the virtualized C-RAN, in which network function virtualization and software defined networking technologies are deployed to virtualize network functions and resources. The virtualized C-RAN architecture consists of digital units (DU cloud), a time-wavelength-division multiplexed passive optical network (TWDM-PON), fronthaul and virtualized base stations (V-BSs) [28]. The DU Cloud performs baseband processing, which are interconnected for data and control packet exchange, which can be regarded as the central unit (CU). V-BSs share the optical link capacity through TWDM-PON. Another variant of C-RAN is the fog radio access networks. In this architecture, cloud computing capabilities are pushed closer to the users. Hence, it enables computing, communication and computation, network decision and control functions placed at the edge of the network to decrease the latency [26].

When considering 3D wireless networks, each of RAN architectures has pros and cons. In C-RAN, all network functions are centralized to have a complete overview of the network; however, it leads to certain requirements depending on the functional splits. Heterogeneous and virtualized RAN architectures provide flexibility in network control by decoupling data and control planes and virtualizing network resources. These architectures may be useful to be employed in 3D holistic networks where there are heterogeneous network nodes such as UAVs and satellites. Fog RAN architecture becomes advantageous when serving IoT nodes on the ground by the space-borne and airborne network nodes.

Open RAN emerges as a RAN specification to use open interfaces and disaggregated functionality over vendor neutral hardware. Open RAN provides openness through open interfaces to enable customization of the network and intelligence at every layer of the network to enable optimized closed loop automation [27]. Another feature of Open RAN is the virtualization of network functions and operation through different split options. Disaggregation in O-RAN enables to divide BSs across multiple nodes in the RAN [28]. Hence, BSs are logically separated into different nodes for RAN functionalities which are radio units (RUs), distributed units (DUs) and central unit - user plane (CU-UP) and central unit - control plane (CU-CP). These units are connected through interfaces defined by O-

RAN and 3GPP. RUs are connected to DUs via open fronthaul links, DUs are connected to the CU over the F1 interface. E1 interface connects user and control plane at the CU.

One important feature of O-RAN is the new functionality named as Radio Intelligent Controller (RIC). xApps in the RIC Near Real-Time (Near-RT) layer enable intelligent radio resource management and quality of service management [27]. It also has the ability to leverage intelligence in RAN functions such as quality of service management, connectivity management and seamless handover management [27]. RIC Near-RT is connected with RAN via E2 interface to control the aforementioned functionalities. A1 is the interface connecting orchestration and automation layer and the RIC Near-RT layer. Open-Cloud consists of pooled resources for computing and virtualization infrastructure from one or several data centers [29]. The interface that connects the management and orchestration functionalities with the cloud is O2 interface. In the 6G-SKY project, O-RAN will be an important architecture to consider due to its flexibility and open interfaces.

6G end-to-end (E2E) system architecture proposals aim native support for intelligence inclusion to use infrastructure resources in a better way, facilitate data governance, system orchestration and management, as well as mobilize the enthusiasm of all stakeholders [29]. 6G system should bring AI from the central cloud down to the mobile communication system and everyone can have the same capability to be able to access intelligent services anytime and anywhere [29]. Running AI at any possible location in a distributed manner may boost federated learning. Furthermore, AI helps 6G to realize enhanced network performance in terms of throughput, latency, etc. via online optimization.

For AI-native architectures, communication and computational resources must be integrated effectively so that the network can achieve real-time learning and inference. For instance, the authors in [30] proposed an AI-native architecture for network slicing in satellite, air and ground integrated networks. AI based solutions are proposed to manage the network slices in an intelligent manner, which is called AI for slicing. Furthermore, the authors proposed network slicing to support AI services, which include constructing and selecting AI instances and efficient radio resource management in AI services.

3 Capabilities required for network architectures for low altitude aerial platform

3.1 Joint sensing, communication and computation in 3D

Capacity, speed and cost of communication links and computational nodes and various implementation options for radio, core-network, as well as management functions for architectural options are discussed below.

The joint communication and sensing operation can be grouped around two main functionalities, such as when the network itself is a sensor or the network serves as communication medium for various sensors or sensor groups. These functionalities are merged in many use cases, e.g., a sensor network comprising a swarm of drones can be connected by another sensing network, but the two roles can be examined as separate topics.

1. Communication network as a sensor

   Electromagnetic radiation and reception enable the communication nodes to observe their environment either actively or passively. Active sensing is when the transmitter and receiver components act in a coordinated manner, while passive sensing is when the receiver only observes electromagnetic radiation arriving potential targets. The targets can be spatially concentrated, point-like targets such as user devices or network nodes. Targets can be any metal, or other electrically conductive objects, for example terrestrial, sea and air vehicles provide sufficient visibilities. Larger reflective surfaces, such as walls or entire buildings, water bodies, snow and ice surfaces or other clutter type reflectors, such as vegetation can also be potential targets. Monitoring some volume scatterers, such as rain, cloud, vapor or biomass might be of interests in specific sensing use cases [31].

The sensing scenarios can be sorted based on the sensing geometry, namely how the transmitter, receiver and target are situated and how fast the geometry is varying. Both the monostatic and bistatic geometries have their specific technical challenges, for example, in synchronization or in interference suppression. If low-Earth orbit satellite nodes are involved in sensing, multiple satellites on precisely known trajectories can cooperate and hence enhance the sensing capabilities. A special use case of 6G-SKY is the collaborative sensing by drones flying in swarms. The models of the observed objects, the explored environment, or even the drone swarm itself are gradually built up from the many observations spread in time and space.

Simultaneous localization and mapping (SLAM) techniques in the optical domain are commercially available but they are only conceptional in civil telecommunication networks [32]. Radio SLAM can augment Global Navigation Satellite Systems (GNSS) and optical navigation in case of bad visibility, shadowing or jamming. Airplanes and drones equipped with directional and steerable antennas can track specular reflections of telecommunication signals and use the directions and signal strengths of reflected signals to compute their own position and attitude. SLAM can be fully autonomous, opportunistic when the device performing SLAM does need assistance from the network or it can be synchronized with the network in such a way that transmitters on the network side send directional signals, e.g., via beam-forming, to potential reflectors. In the latter case, beam scheduling has consequences in network architecture.

2. Network connecting sensors

   Aerial and ground users can serve as sensors in the network. These “sensors” have joint communication and sensing capability. For example, a UAV with radar sensing capability can sense targets in 3D and sends its observation to a ground BS or other aerial platform with better computation capability. Furthermore, ground terminals such as agribots in rural areas can have the joint communication and sensing capability to sense the presence of objects. These ground terminals may have direct communication with aerial and space-borne platforms to transmit sensed data to a computationally more capable network node. The transmission of raw sensing data is not efficient due to their high data volumes. The network connecting these sensors have different levels of decision making after the data fusion from these sensors.

To integrate sensing functionality into the communication network [33], new functions should be added both to the radio and core networks. The sensing request may arise internally in the network or triggered by external demand. Two basic sensing requests are common, one is to track specific targets, another to survey an area. An important case from the viewpoint of privacy is if the sensing involves UEs, especially, if the UEs belong to persons.

Figure 7 depicts the network components that may provide a framework for network sensing. Some of these components are novel and may be realized in a different format than how it is presented here, but the main functional tasks remain the same.

The central element of the sensing architecture is the Sensing Management Function (SeMF) which takes sensing requests from external clients and organizes network sensing targets. Sensing tasks may arise internally in the network, such as the network performs periodic surveys or pre-scheduled scanning of the environment over a given spatial domain in part time, while it conducts its regular communication tasks. The sensing data collected in such cases do not necessarily involve users, since the network only progressively discovers, monitors the environment often by applying AI/ML. SeMF may have the intelligence to organize the sensing procedures itself according to higher-level objectives such like searching for targets or monitoring changes in the environment. SeMF is also prepared to receive sensing tasks from external clients. Then, all the internal and external sensing tasks are listed and tracked in a Sensing Task List (SeTL), which includes the status, as well as, the final or partial results of the sensing task which the SeMF can query or notified by callback. The sensing task may extend in time and may produce a model of some environmental phenomenon. If UEs are involved in the sensing operations, SeMF should check with the Authentication Server Function (AuSF) for permission. If permission is given, then the information exchange regarding the whereabouts of the involved UEs will be conducted with the Access and Mobility Function (AMF). AuSF and AMF are legacy 5G functions, which should be prepared for such novel kinds of information exchange with the sensing functions. Sensing needs UE positions but can also improve UE positioning in exchange.

SeMF conveys the sensing tasks to a novel RAN node, to the Sensing Controller (SeC), whose task is to match the sensing task with RAN resources, then works out the measurement details for RRM and delegate the detailed subtasks to one or more Sensing Schedulers (SeSch) each having its own regional scope on a territorial basis. SeSch nodes are best placed in regional computation facilities talking to network nodes in the surroundings. SeSch schedules the sensing operation on L2 level, it decides on the timing, frequency bands and beams to be used in a coordinated fashion in the RAN nodes involved in the local sensing operation.

In the return path, SeSch collects, aggregates, and combines the sensing measurement results from the network nodes it is connected to, then SeSch reports the preprocessed measurements to SeC. SeC then assembles the big picture from the territorial pieces received from the SeSch nodes. Such evaluation result at this level could be like detection, size- and location estimation of targets and if the task happens to be target tracking for instance, then SeC is responsible to reallocate RAN resources to the instantly modifying sensing task. Upon getting to some conclusion on a given sensing task, SeC communicates the results to SeMF, which evaluates the sensing results, incorporates those in an environmental model or determines the observed properties of the target. If the sensing task was originated from an external request, then SeMF delivers the results to the requester.

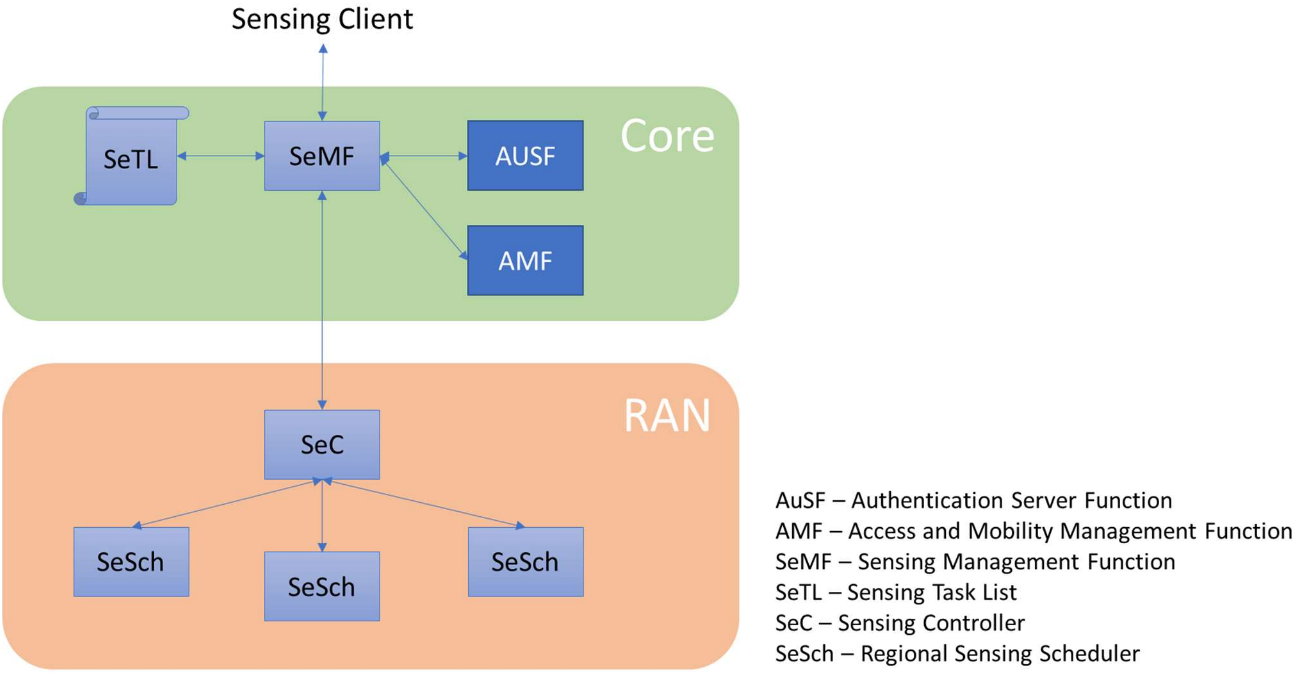

Figure 7: Sensing-related network elements in a 6G network architecture

Joint communication and sensing studies in 6G-SKY need to focus on some extra requirements, which have not got emphasis in earlier works [34]. Such an aspect is that by involving NTN nodes in sensing, the nodes involved in sensing may also move. Hence, accurate positioning and synchronization of the transmitter and receiver components are as important as ranging and sizing the target. Mobility makes an even tougher challenge in case of distributed, cooperating sensors, such as drone swarms.

Another important area of research and system design is the ingestion and management of sensing data both at the level of SeSch and that of SeC nodes. The potential solution, a distributed database, is a collection of multiple interconnected databases that are geographically distributed over a network. It enables data to be stored, accessed, and processed in a distributed manner, which helps to increase scalability, availability, and fault tolerance of the system.

In a multi-operator setting, the access control, data privacy and adequate data retention policy are of paramount importance for a reliable joint sensing system. In case raw data cannot be shared between certain parties, the federated analytics of the sensing data may still offer remedy: federated analytics is a privacy-enhancing technique used in data analytics that allows multiple organizations or entities to collaborate on analyzing their data while keeping the data local and private. Traditionally, data analytics involves collecting data from various sources, aggregating it, and analyzing it to extract insights. However, this approach can pose privacy risks and concerns, especially when sensitive data is involved. Federated analytics, on the other hand, enables organizations to share insights without sharing the underlying data. In federated analytics, each organization retains ownership of its data and only shares insights or aggregated results with other organizations. This is achieved by using advanced encryption techniques and other privacy-preserving methods that allow the data to be analyzed without being exposed to unauthorized parties.

Furthermore, joint communication and computation in 3D creates the need for federated learning, a machine learning technique that enables multiple devices to collaboratively train a model without sharing their data. It is particularly useful for applications where data privacy is a concern or where the data is distributed over a large number of devices or largely separated in space, as in satellite networks. Federated learning can help to improve the accuracy of models and reduce the computational load on individual devices. E.g., when it comes to the distributed computation of 3D coverage, where the optimization target could be the aggregation of quality of service (QoS) metrics such as coverage, throughput, and latency, or a weighted utility function that takes into account the importance of different QoS metrics, federated trained models can potentially translate the constraints, e.g., the capacity, rate, and cost of communication links between devices, as well as the computational resources available on each device, into quasi-optimal network settings. Such optimization efforts go into the correct handling of the aforementioned mobility of NTN nodes, not only in sensing use cases, but also in the case of simple handovers of client sessions. Energy-saving mode refers to a low-power state that such devices can enter to conserve battery life. It is important to coordinate access links provided by drones in a way that maximizes the amount of time that devices spend in energy-saving mode, while still ensuring that the network remains stable and reliable.

In terms of architectural elements, distributed database, analytics and learning all require dedicated nodes at each and every autonomous provider of the ecosystem. Data transfers are then performed over traditional protocols, e.g., HTTP towards REST APIs.

3.2 Safe and explainable AI for adaptive and robust communications

Many industries (including aviation, see EASA [3]) consider AI in critical operational contexts. AI can act on physical, data link, network, and application layers in 6G. It is a candidate for 6G to accomplish dynamically allocating resources, changing traffic flows, and processing signals in an interference-rich environment [4]. 6G appears to be attractive to aviation, since it enables efficient connectivity by terrestrial and non-terrestrial networks. On the one hand, aviation can potentially profit from AI-optimized 6G networks to achieve performance parameters (transmission reliability, data rate, etc.). On the other hand, implications for 6G services by AI-based networks that are used for critical aviation tasks need to be risk assessed. If possible, the network itself ensures the fulfillment of service parameters (e.g., defined in an SLA). If a network fails in fulfillment of service parameters (e.g., a longer disconnect during a flight), the following questions arise:

- How can the AI decisions be explained afterwards to avoid such disconnections (offline case)?
- How can the AI decisions be explained and handed over to the flying vehicle such that the flying vehicle does corrective actions, such as other flight levels (online case)?
- How can such failure events be predicted?

AI-based methods that aim to maximize the long-term objective rewards, require zero human intervention and could thus reduce the operating expense. However, a robust and secure AI system should not only work under normal circumstances, but also provide reliable predictions even with out-of-domain samples. First, the Trustworthy AI system should be able to identify the type of the risks. For instance, the system should be able to determine the reasons that caused disconnections of UAVs (collisions, severe interference or power depletion). Once the disconnection happened, the system reports interpretable information (like the ID and location of the disconnected UAV) to the human end-user for the follow-up support. Second, the disconnected UAV (if it still has on-board power) switches to the autonomous mode and flies to the nearest support center while avoiding colliding with other UAVs. The system then keeps learning with data aggregated by the remaining UAVs without being influenced by the disconnected UAV. Third, the AI system should provide available actions to the human operator to mitigate the influence of the risk.

To make the decisions of the AI system more explainable to the nontechnical end-users, text explanations that use texts to explain the algorithms' rationale and visual explanations that use visual representations of the internal system behaviors can be adopted. Note that these two explanations can be delivered at the same time for a better comprehension of the system. A map that corresponds the text or visual symbols with the decisions of the artificial intelligence (AI) system should be formulated.

To predict and avoid failures, the AI system will closely monitor the input data, the system dynamics while learning to extract generic failure information. For instance, the power level of each UAV should be reported to the system periodically to avoid depletion. The running out of battery can be predicted in advance and actions can be taken before the risk happens. The AI system should also employ all available information to help predict the possible risks (like weather forecasts to predict extreme weather) and automatically switch to the learning mode that is crafted for such conditions. The design of the AI system should take all the possible risks into consideration and study the most informative feature of each risk and summarizing conditions of failure such that the potential risks can be reduced as many as possible before they happened.

As AI-powered wireless infrastructure is critical, the respective decisions made by AI impact network services and use cases such as urban air mobility. Hence, we need a wider approach to enable trust via accomplishing functional criteria related to the system behavior and non-functional criteria such as KPIs and costs [35]. As there is always a risk associated to machine learning algorithms, we need a framework to predict and manage associated risks. Hence, systematic and holistic approaches are needed to encompass trustworthy AI mechanisms in 3D NTNs. To this end, novel metrics should be defined to quantify the risk of decision making for the wireless connectivity of the flying vehicles. Main goal is to enable robust connectivity through trustworthy AI with KPIs such as availability, reliability and continuity.

The centralized network architecture can decrease the interference from UAVs on uplink communications of coexisting terrestrial users, and the frequent handovers for UAVs. This architecture can incorporate different sources of rewards and regrets with respect to the network resources, and KPIs of drone users and interference to ground BSs. We can have some performance guarantees due to centralized network control. For NTNs, there are numerous flying vehicles with different requirements of the aerial communication links. For instance, control signaling of these vehicles may become prohibitive and may cause delay and convergence issues. Furthermore, we need to manage 3D mobility with different types of flying vehicles, which leads to scalability issues and stringent requirements on availability and reliability. Also, the focus should not be only uplink but also downlink communication to guarantee the safety of flying vehicles due to feedback mechanisms for decision making.

One approach is to have a hierarchical network architecture such that we enable different decisions such as radio resource provisioning, scheduling and utilization at different levels such as satellite, HAPS and ground base stations. In such a hierarchical network architecture, transfer learning may be utilized to share machine learning models in different parts of the network. Federated learning is an important tool to leverage the huge volumes of available records of requests/responses at the edges for extracting common rules and policy sets, which decreases the amount of data to share for training, only parameter sharing and provides more secure model sharing. Risk-aware learning from past decisions is also a good strategy to minimize service outages such that we avoid events with huge losses, e.g., missing URLLC packets.

To summarize, from an architectural point of view, the inclusion of the AI Trustworthy aspects highlighted above must be part of the AI life-cycle. In the AI life-cycle, we typically differentiate between three phases: business and data understanding, model development and model operations. It is fundamental to evaluate and implement existing tools, as well as develop new ones, and understand how they can be integrated on the AI life-cycle. This is fundamental to achieve safe and reliable communications.

4 Holistic adaptive combined ASN networks and TN architectures with multi-technology communication links for 6G

The 6G-SKY project aims at providing an architecture for limitless connectivity to all aerial platforms at different altitudes and users on the ground through its holistic network architecture that combines terrestrial networks, airspace and non-terrestrial networks. The below figure shows the overall 6G-SKY architecture, which captures all airborne and space-borne platforms with the related terrestrial infrastructure. One important aspect of the 6G-SKY architecture is the utilization of multiple communication links such as satellite communication links, HAPS/HIBS communication links, air-to-air communication (A2AC) links, and direct air-to-ground communication (DA2GC) links.

As the aerial and ground users have different quality of service (QoS) requirements, multi-connectivity with different communication technologies are employed. For instance, flying or air taxi in the below figure have DA2GC, A2AC and satellite communication links as the requirements are very demanding. Another feature of the 6G-SKY architecture is its adaptability to the network topology changes due to 3D mobility as the network elements may have different speeds, which causes changes in the link dynamics. In the following subsections, we provide more detailed information regarding the architectures focusing on different communication platforms.

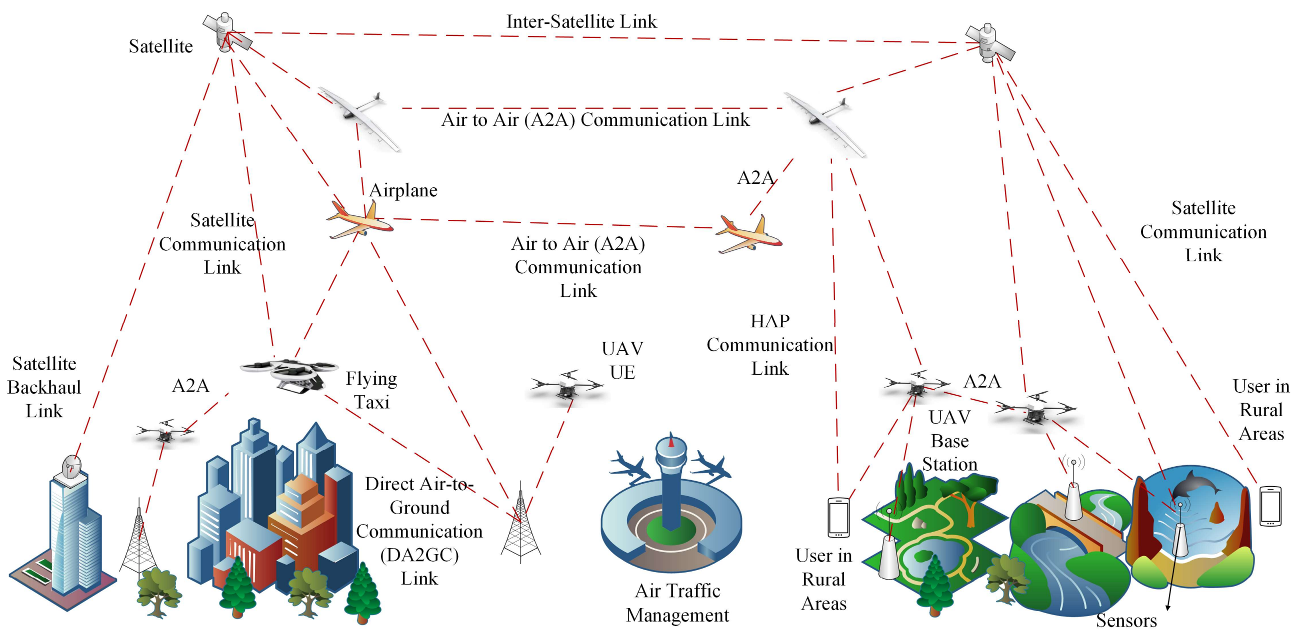

Figure 8: Holistic combined ASN networks

4.1 Network architectures with multi-technology communication links, comparison of different options

A communication analysis has been conducted for the low altitude aerial platforms for drones, air taxi and airplanes. The communication analysis has been done in two steps: A) an analysis of the communication cases for the particular aerial platform, B) a mapping of potential technical solutions towards the particular aerial platform. The benefit of this analysis is to show that communication cases can be similar between aerial platforms but with different characteristics requirements. There is an opportunity to align technical solutions between aerial platforms.

4.1.1 Communication analysis for drone aerial platforms

A communication analysis has been done for the following aerial platforms: drones, air taxi and commercial aircraft, which are the main focus of this deliverable.

4.1.1.1 Analysis of communication cases for drones platforms

Eleven communication cases have been identified for drones, which are outlined in the figure below:

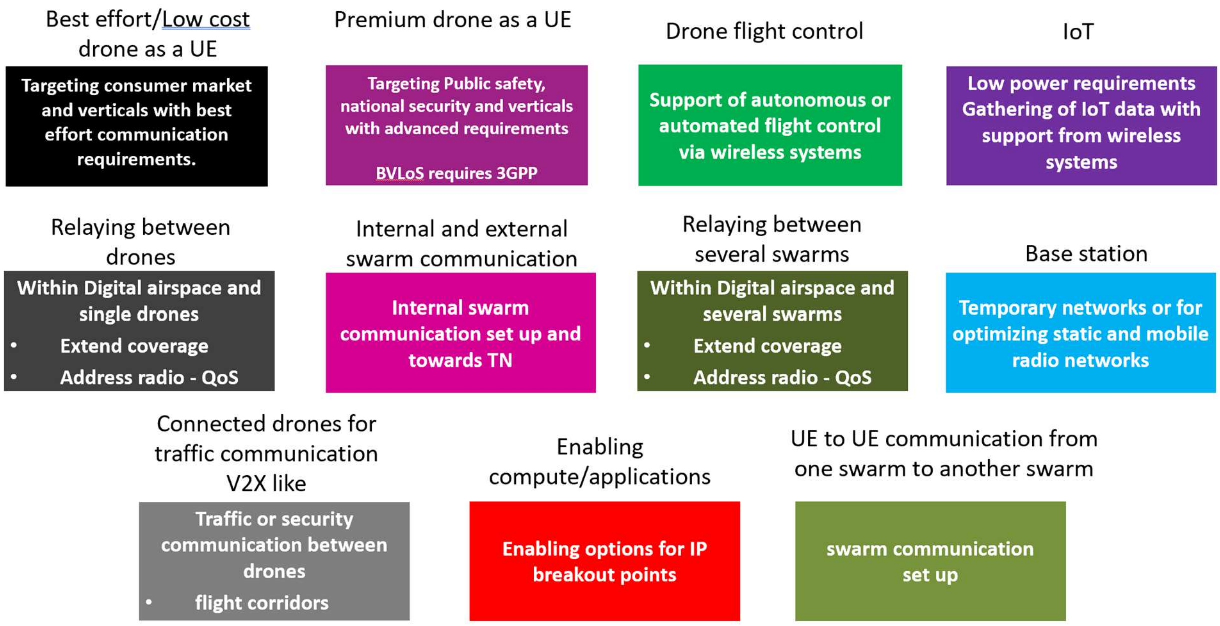

Figure 9: Communication cases for drones.

We have divided drones as UE in two main categories: best effort and premium drones; these drones basically addresses different market demands.

The best effort drone/low cost drones target the consumer market and industry verticals with best effort requirements. Many times these solutions have LOS condition and is addressed with point to point connections. The drone flight control is via local proprietary radio protocols or via WiFi. The drone will most likely carry a mobile UE device.

The premium drones target public safety, national security and verticals with advanced requirements. Many times these solutions consider beyond visual line of sight (BVLOS) scenarios and can allow more advanced technical solutions, e.g., radios and functionality such as beamforming. The drone will have UE functionality.

The drone flight control use case is valid for BVLOS scenarios where there is an interest to support autonomous or automated flight control via wireless systems. Depending on the setup, communication requirements can range from semi-real time support to stringent real-time support.

IoT is a special use case which is all about supporting low power requirements to prolong battery time for devices. In this use case, a drone can aggregate IoT device data with a support from the wireless system.

Another communication case for drones is the need for relaying between drones or from drones to other aerial platforms. One reason for this is to extend coverage areas with poor radio connections. It can also be that the connection for the drone to the terrestrial network has QoS issues and that QoS can be improved by relaying traffic through another drone that has better drone to terrestrial network (TN) connection.

Drones can form swarms. There is a need for two types of communications for drones; within the swarm and to/from the swarm to the terrestrial network.

Another communication case for a drone is to serve as a mobile base station that can either provide temporary coverage capabilities or improve radio characteristics in a certain area.

The connected drone for traffic or security communication case is similar to 4G/5G V2X for cars. There could even be an interaction between cars and drones supporting V2X communication where cars and drones interact. Drones can relay information from one car to another. For drones, flight corridors similar to corridors for commercial airplanes might be regulated which open up for V2X like communication between drones inside the flight corridor.

On a drone, compute and application capabilities can be added. This is affecting traffic streams and given options on how the drone and the terrestrial network communicate. On the payload level, the placement of IP breakout points affect the traffic streams. A wireless system communicates with an external data server via User Plane Function (UPF in 5G system). Therefore, the placement of the UPF affects traffic streams.

A special communication case for swarms is when a drone UE within a swarm wants to communicate with another Drone UE in another swarm. That communication can to various levels involving the terrestrial network. IP breakout points can e.g. be placed on swarm level. The technical solutions for achieving this is further elaborated in Chapter 4.1.1.

4.1.1.2 Mapped technical solutions towards communication cases for drone platforms

Below follows a table showing technical solutions mapped towards drone platforms:

Communication scenario / Technical solution	1. Drone as UE: best effort/low cost: LoS	2. Drone as UE: Premium effort/Higher cost. TN access link (opens up for BvLoS)	3. Drones with requirements on TN support for autonomous or automated flight control	4. Drone: Targeting IoT with low power requirements	5. Relaying between Drones Most likely advanced drones)	6.Drone communication within a swarm with a master drone and donor drones	7. Relaying between master drones of several swarms	8. Drone as a base station	9. Connected drone and/or integrated connected drone/car traffic & security communication
TN Access link with wifi or Local Proprietary radio (non 3 GPP)	X	X							
TN Access link/backhaul with 3GPP	X	X	X	X	X	X	X	X	X
IAB						X		X	
V2X					X	X	X		X
Sidelink					X	X	X		X
L2 Relaying (No Beamforming)					X	X			
L2 (beamforming)					X	X	X		
L3					X	X	X		
L1					X	X	X		

Figure 10: Technical solutions mapped towards drone communication cases 1(2), for 2(2) see Figure 12.

This figure shows technical solutions mapped towards the communication cases for drones.

In communication cases 1 & 2, there is an opportunity to control the drone with Wifi/local proprietary radio solutions. This could even be so far taken that a 3GPP based network is not used. The access network could be a fixed connection instead e.g. a fiber connection. If you add UE capabilities to the drone UE, then an access link must be added between the TN and the Drone UE.

In Communication case 3, the access link is needed to support BVLOS communication with the drone. This is due to that flight paths for the drone will most likely be further than LOS conditions and may cover several cells.

Communication case 4 requires a configuration of IoT features from the TN to preserve battery life time in IoT devices. Drones can aggregate and relay data provided by IoT devices but there is also a potential to add compute and application capabilities to the drone, if there is a need to send aggregated data from the drone to IoT applications in the TN network. The reason to add local analytic capabilities is to limit data sent into the network and simplify processing at the central unit.

In Communication case 5, we have a need to relay data between two drones. This can be done on different levels, L1, L2 or L3 level:

- L1 covers the physical level. The relay node takes the received signal, amplifies it and forwards the signal to the next hop.
- L2 covers Phy, MAC, RLC. Relays can demodulate and decode the received signal and re-encode and re-modulate again. Higher layer signaling are transparent to the relay UE.
- L3: Relay node has the same functionality as that of the base station. The relaying control is left up to the application layer. The user data is processed up to the application layer.

In Communication case 6, internal swarm communication open up a further choice of relaying techniques: IAB, V2X or sidelink alternatives. V2X and sidelinks are currently short-range techniques.

Communication case 7 is similar to communication case 5, but in this case we have relaying between two master drones for two different swarms.

In Communication case 8, the drone acts as a base station. Then, the drone could be a traditional base station with a backhaul link to the TN or become an IAB.

Communication case 9 supports traffic and security communication between two drones or between a drone and cars. There are a couple of technologies available for this such as V2X and sidelink.

Below follows a figure for drone communication case 10 and 11:

Communication scenario / Technical solution	10. Drone with capabilities to handle compute and applications	11. Communication from one UE within a swarm to another swarm with another UE
IP Break out point in drone (UPF) User plane in Drone Core control plane in TN	X	
IP Break outpoint in drone UPF up in drone. Core control partially or full deployed at drone	X	
IP breakdown at ground (UPF) UPF on the ground	X	
IP Break out point in Master drone (UPF) User plane in Drone Core control plane in TN		X
IP Break outpoint in Master drone UPF up in drone. Core control partially or full deployed at master drone		X
IP breakdown at ground UPF on the ground		X
TN Access link with 3GPP (optional)	X	X

Figure 11: Technical solutions mapped towards drone communication cases 2(2).

Both communication cases 10 and 11 deal with where to place IP breakout points and mobile packet core functionality in the network.

In Communication case 10, there is a need to add compute and applications capabilities on the drone to interact with the wireless system. The case that requires most communication between the drone and TN would be if the IP breakout point is placed in the TN, i.e. the UPF. This would require communication towards the application to go via the UPF. Another alternative is to place the IP breakout point in the drone, i.e. UPF in the drone. The UPF would enable the user plane to be handled in the drone, but you can still have the mobile packet control plane in the TN. The third alternative is to also move core control functions partially or fully to the drone. Then, both user and control plane would be located in the drone.

A similar discussion can be made for communication case 11. If a UE has both user plane and control plane supported by the swarm then communication between two UEs may not need the TN. If the user plane is located on the swarm and the control plane in the TN, then the payload communication can be between the swarms.

If the IP breakout point is put in the TN, the TN will relay data communication between the swarms and handle the control communication.

4.1.2 Communication analysis for air taxi aerial platforms

The communication cases for air taxi platforms have similarities with those ones for drones. What is really being added is the communication case for cabin communication for an air taxi.

4.1.2.1 Analysis of communication cases for air taxi platforms

Below follows a table showing communication cases for air taxi platforms:

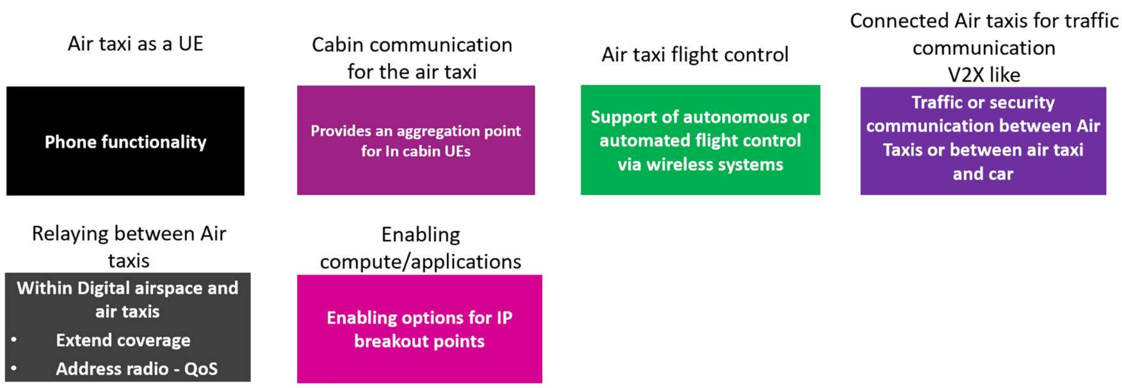

Figure 12: Air taxi communication cases.

The first communication case for an air taxi is having the same functionality as a mobile phone. In air taxis, a UE can be integrated into the cabin.

The second use case is cabin communications. In this communication case, the air taxi facilitates internal UE communication and provides an aggregation point for the UEs of passengers. From the aggregation point at the air taxi traffic, the data is transferred via the backhaul link to towards the TN.

The air taxi flight control use case is valid for BVLOS scenarios where there is an interest to support autonomous or automated flight control via wireless systems. Depending on the setup, communication requirements can range from semi-real time support to stringent real time support with high QoS requirements. The semi real time support depends on how much flight path planning is downloaded to the air taxi and also on how detection collision and action is managed. If a lot of the intelligence is put decentralized into the air taxi the need of central updates to the flight path will be reduced, but still periodic status monitoring in the range of one second with low data rate is required by the air traffic control.

The connected air taxi for traffic or security communication case is similar to V2X for cars. There could even be an interaction between cars and air taxis supporting V2X communication, where cars and air taxis interact. Air taxis can relay info from one car to another similar to a Road Side Unit (RSU). For air taxis, flight corridors might be regulated which opens up for V2X like communication between air taxis in the flight corridor.

There is also a need to relay data between air taxis. This communication case can address the need for extending coverage in areas with poor radio connections, e.g., at the cell edge on ground (whereas connectivity is possible in the air). It can also be that the connection for the air taxi to the terrestrial network has QoS issues and that QoS can improve by relaying traffic through another air taxi that has better QoS to TN connection.

The communication case for enabling compute and applications on an air taxi, deals with where to place IP breakout points and mobile packet core functionality in the network.

4.1.2.2 Mapped technical solutions towards communication cases for air taxi platforms

Below follows a figure showing technical solutions mapped towards air taxi platforms:

Communication scenario / Technical solution	1. Air taxi as UE	2. The air taxi facilitates cabin communication within the air taxi and facilitates TN access link	3. Air taxi with requirements on TN support for autonomous or automated flight control	4. Connected air taxis and/or integrated connected air taxis/car traffic & security communication	5. Air taxi to air taxi relaying communication
TN Access link with 3GPP	X	X	X	X	X
IAB		X			
Mobile Wifi Router with advanced connection to antenna		X			
V2X				X	X
Sidelink				X	X
L2 Relaying (No Beamforming)					X
L2 (beamforming)					X
L3					X
L1					X

Figure 13: Technical solutions mapped towards air taxi communication cases 1(2).

Communication case 1 require an access link between the air taxi and the TN.

Communication case 2 requires that the air taxi facilitates in cabin communication. This can be done with several technologies. One solution is IAB. Another solution includes a mobile router that aggregates passenger traffic. Between the air taxi and the TN, an access link is required.

Communication case 3 for air taxi flight control requires an access link. This will enable BVLOS communication. This is due to that flight paths for the air taxi will most likely be further than LOS conditions and may cover several cells.

Communication case 4 supports traffic and security communication between air taxis or between an air taxi and cars. There are a couple of technologies available for this such as V2X and sidelink. V2X and sidelinks are currently short-range techniques.

Communication case 5 supports relaying between two air taxis or towards other aerial platforms. A set of relaying alternatives exist ranging for L1, L2, and L3, e.g. based on sidelink communication with relaying functionality.

Below follows a figure for drone communication case 6:

Communication scenario / Technical solution	6. Air taxis with capabilities to handle compute and applications
IP Break out point in Air taxi User plane in Air taxi Core control plane in TN	X
IP Break outpoint in Air taxi UPF up in Air taxi. Core control partially or fully deployed at Air taxi	X
IP breakdown at ground UPF on the ground	X
TN Access link with 3GPP	X

Figure 14: Technical solutions mapped towards air taxi communication cases 2(2).

Communication case 6 deals with where to place IP breakout points and mobile packet core functionality in the network. Three alternatives exist, see figure:

- IP Breakout point in the ground
- IP Breakout in the air taxi
- IP breakout in the air taxi, but with the addition that core control can partially or fully be deployed at the air taxi.

4.1.3 Communication analysis for airplane aerial platforms

The communication cases between air taxis and airplanes are similar. However, the commercial airplanes usually have hundreds of passengers while air taxi have a smaller number of passengers. Typically, air taxis are planned to carry less than 10 passengers.

4.1.3.1 Analysis of communication cases for airplane platforms

Below figure shows communication cases for airplane platforms:

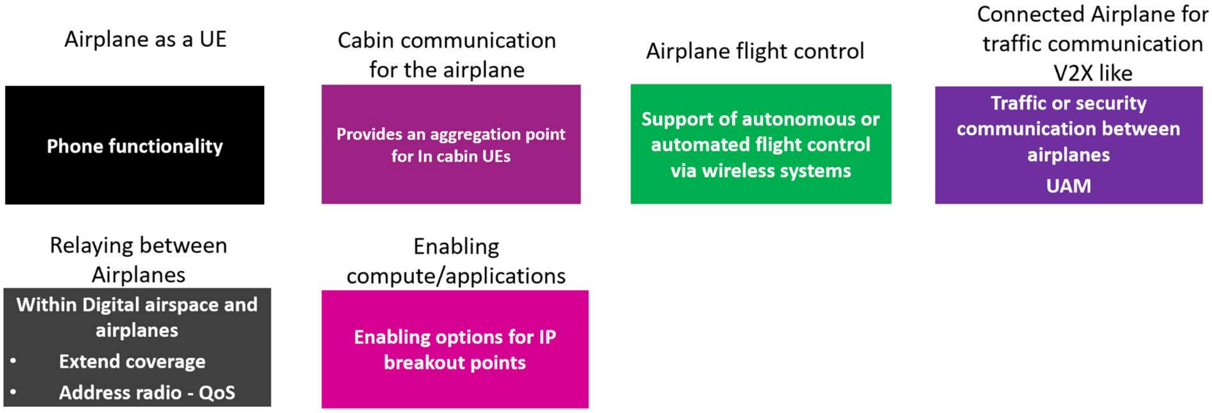

Figure 15: Communication cases for airplanes.

The first communication case is for an airplane having the same functionality as a mobile phone, which could be used for pilot communication.

The second use case is cabin communications. In this communication case, the
the airplane facilitates internal UE communication and provides an aggregation point for the UEs of passengers. From the aggregation point at the airplane traffic, the data is transferred via the backhaul link to towards the TN.

The airplane flight control use case is valid for BVLOS scenarios where there is an interest to support autonomous or automated flight control via wireless systems. Depending on set up, communication requirements can range from semi-real time support to stringent real time support.

The connected airplane for traffic or security communication case is similar to V2X for cars. There could even be an interaction between airplanes and air taxis supporting V2X communication. For airplanes, certain flight corridors can be enforced which open up for V2X like communication between aerial vehicles in the flight corridor, e.g., to inform about traffic within the flight corridor.

There is also a need to relay data between airplanes. This communication case can address the need for extending coverage in areas with poor radio connections. It can also be that the connection for the airplanes to the terrestrial network has QoS issues and that QoS can improve by relaying traffic through another airplane that has better airplane to TN connection. The relaying can support various services such as mobile broadband.

The communication case for enabling compute and applications on an airplane, deals with where to place IP breakout points and mobile packet core functionality in the network.

4.1.3.2 Mapped technical solutions for airplane platforms

Below follows a figure showing technical solutions mapped towards airplane platforms:

Communication scenario / Technical solution	1. Airplane as UE	2. The airplane facilitates internal UE communication within the airplane and facilitates NTN and TN transfer of data via the accesslink	3. UE Airplane with requirements on TN support for autonomous or automated flight control	4. Connected airplane to airplane traffic & security communication	5. Relaying between Airplanes and other aerials
TN Access link with 3GPP	X	X	X	X	X
Mobile Wifi Router with advanced connection to antenna		X			
IAB		X			X
V2X				X	X
Sidelink				X	X
L2 Relaying (No Beamforming)					X
L2 (beamforming)					X
L3					X
L1					X

Figure 16: Technical solutions mapped towards airplanes communication cases 1(2).

Communication case 1 require an access link between the airplane and the TN.

Communication case 2 require that the airplane facilitates in cabin communication. This can be done with several technologies. One solution is IAB. Another solution includes a mobile router that aggregates passenger traffic. Between the airplane and the TN, an access link is required.

Communication case 3 for airplane flight control requires an access link. This will enable the BVLOS communication. This is due to the fact that flight paths for the airplane will most likely be further than the distance supporting LOS conditions and may cover several cells.

Communication case 4 supports traffic and security communication between airplanes or between an airplanes and air taxis. There are a couple of technologies available for this such as V2X and sidelink. V2X and sidelinks are currently short-range techniques.

Communication case 5 supports relaying between two airplanes or from an airplane to another aerial platform e.g. satellites. A set of relaying alternatives exist ranging for L1, L2, and L3. For further elaboration, please see Ch 4.1.1.2.

Below follows a figure for drone communication case 6:

Communication scenario / Technical solution	6. Airplanes with capabilities to handle compute and applications
IP Break out point in Airplane User plane in Drone Core control plane in TN with support from TN	X
IP Break outpoint in Airplane UPF up in Airplane. Core control partially or fully deployed at Airplane	X
IP breakdown at ground UPF on the ground	X
TN Access link with 3GPP	X

Figure 17: Technical solutions mapped towards airplanes communication cases 2(2).

In Communication case 6, there is a need to add compute and applications capabilities on the airplane to interact with the wireless system. The case that requires most communication between the airplane and TN would be if the IP breakout point is placed in the TN, i.e. the UPF. Another alternative is to place the IP breakout point in the airplane, i.e. UPF in the airplane. The UPF would enable the user plane to be handled in the airplane, but you can still have the mobile packet control plane in the TN. The third alternative is to also move core control partially or fully to the airplane. Then, both user and control plane would be located in the airplane.

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

In 6G-SKY, UAVs and UAV swarms are on one hand part of the application equipped with application specific sensors, processing hardware and algorithms. On the other hand, they are part of the 6G-SKY communication architecture providing connectivity in remote areas or among themselves. The communication architecture and also the way the UAVs are coordinated as a team or swarm performing a common mission strongly depend on the application.

In 6G-SKY, we consider a cargo hub with an underlying use case, described in D1.1 in further detail, as a first representation of autonomous mobility and infrastructure. This represents a rather typical application setup that can be found in other applications as well, namely eMBB type communication for payload data (or processed information) a) between UAVs and b) entities outside the swarm (base stations, other (mobile) carriers).
On top of this, machine type communication has to take place between UAVs and a central control instance or even other autonomous entities (autonomous ground vehicles, etc.) to account for the exchange of control data. Whereas the former type of communication is often delay tolerant, more or less strict real-time conditions exist for the latter.

We propose a versatile architecture for a 6G-SKY drone swarm that can be used in rural areas for various applications. This architecture goes beyond the aforementioned cargo hub use case. It also includes coordination of autonomous transport for both goods and people on different rural mobility infrastructures such as rails, streets, and others. Additionally, the architecture should also be able to accommodate infrastructure inspection needs.

The architectural considerations cover four areas: 1) Communication within and outside the swarm, 2) Swarm coordination, 3) UAV hardware (including sensors and processing) 4) Generation of Information.

1) Communication within and outside the swarm and 2) swarm coordination

The basic processing chain on board of a typical robot consists of collecting data about its environment (sensing), processing this data (often including the fusion of different sensor modalities) and acting according to the task at hand. However, in order to take the step from single robot systems to multi-robot systems, additional building blocks are needed, namely: connectivity, communication and coordination [36].

Connectivity includes the basic hardware and software requisites for the wireless interaction between drones. The communication includes the actual data distribution on top of connectivity between robots, while the coordination manages how to allocate and execute tasks on individual drones in order to achieve the intended behavior of the swarm. The principal idea of swarm robotics is to apply nature-inspired behaviors, where the global behavior of the swarm emerges from local rules and local interactions between swarm members. However, most real-world implementations apply centralized control algorithms instead, because the behavior of such centralized algorithms is easier to predict and proof and often the communication architecture also favors centralized approaches [37].

Since both approaches have their merits, the 6G-SKY communication architecture supports centralized control (e.g., using A2G links to ground control stations, or A2A links between a master drone and several donor drones) but also distributed control and decision making by providing ad-hoc connectivity between UAVs (e.g., Meshmerize mesh networks or networks based on technologies such as sidelink communication). Even if the coordination is done in a distributed way, there is often the need for connectivity with central entities such as ground control stations where operators can define new missions or monitor the current state of a mission or Unmanned Aircraft System Traffic Management (UTM) systems.

3) UAV hardware (including sensors and processing)

Depending on the payload and/or flight time requirements, different multi-rotor systems will be provided as seen in the below figure.

„Small“ MTOW: 1,7kg	„Medium“ MTOW: 5kg	„Large“ MTOW: 12kg
OPEN: UAS Class C2	OPEN: UAS Class C3	OPEN: UAS Class C3
Flight time: ~15min	Flight time: ~20min	Flight time: ~35min
Variable payload		
CE-Certification		
Applicable for SPECIFIC and standard scenarios		

Figure 18: Drone types

In total, four drones will be manufactured and selected sensors will be integrated. According to the current status of requirements, three of them will be of type “Medium” and one will be of type “Large”. The exact distribution between Medium and Large is still subject to change and will be settled in the demonstration planning as part of Task 5.1. The drones are highly adaptable and flexible both for hard- and software demands. In order to comply with given legal requirements for the use cases, all necessary certifications are fulfilled.

The sensing and processing unit will consist of a high-resolution optical sensor combined with an edge computing module.

4) Generation of information

Information on the status of the area monitored by the drone swarm will be generated by processing the input of the optical sensor via detection and classification algorithms. Depending on the specific requirements of the monitoring case and the drone swarm’s capabilities, sensor input can be directly sent to a processing base station, preprocessed, or fully processed on the edge computing module carried by the drones. The 6G-SKY communication architecture will support the resulting needs for stable A2G connection of the swarm to the receiving base station, terrestrial transmission of processed information and transmission of the subsequent routing information to remote relay stations and autonomous vehicles via vehicle-to-everything (V2X) links.

5 Sustainability

The information and communications technologies (ICTs) industry play 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 [5]. ICT is the backbone of today's digital economy and has 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

[6]. ICT is crucial for achieving all the 17 SDG goals (displayed in the figure below) and should be considered as a catalyst for accelerating the three pillars of sustainable development: economic growth, social inclusion, and environmental sustainability.

Figure 19: The United Nation's 17 Sustainable Development Goals [5].

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, ICT 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 [7].

In Europe, the SESAR ATM Masterplan predicts a growth of air traffic in the future [38]. However, 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 [8]. 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 aircraft. 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. According to NextG Alliance [39], the ICT industry has an important role to play in reducing Greenhouse Gas emissions. Telecommunications consumes 2-3% of the global electricity supply and the broader ICT industry currently consumes 5-9%, but with the rapid growth in digitization this may rise up to 20% by 2030.

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" [9]. Use cases that will emerge related to 6G and also 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 also 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 [10].

To this end, our 6G-SKY communication architecture will contribute to these sustainability goals that are set by UN and EU. Our architecture will employ new communication solutions to realize transportation in third dimension, which contribute to smart city, smart transportation and digitalization of airspace. Our efforts may be translated into more safe and secure air, which increases the social acceptance of new applications in the sky contributing to economic, social and ecological sustainability. Our 6G-SKY communication architecture has the possibility to open new business opportunity, which may contribute to the economic sustainability through creating new jobs. For instance, the 6G-SKY architecture aims at providing connectivity to remote areas for certain applications ranging from environment monitoring to search and rescue.

One important use case which benefits from our 6G-SKY communication architecture is smart agriculture. As for rural areas, 6G can support precision agriculture, which has the potential to significantly contribute to efforts to address agricultural challenges [11]. Agro-technology and precision farming use data-driven approaches to increase agricultural productivity while minimizing environmental impacts, while being hampered by factors such as a lack of training, a low return on investment, high costs, and a lack of precision agriculture big data analytics. NTN can efficiently support in these agricultural areas by global connectivity to end devices such as tablets (e.g., for farm control or training), farm robots, and UAVs [12].

6 Conclusion

The current advances in aviation and space industries flourish new sets of use cases in the sky in addition to covering the ground via airborne and spaceborne vehicles. To realize this new set of use cases (which are also outlined in Deliverable 1.1), a combined ASN network architecture is needed.

This project report serves to present initial design considerations of the three-dimensional (3D) network architectures.

One aspect to consider in the network architecture is to cover all functional levels to capture visions of SESAR, SES, ITU and NGMN toward 6G. Another aspect affecting the 6G-SKY architecture is the SESAR initiative and its vision to transform airspace into the digital one. 6G-SKY architecture must efficiently manage the communication, computation, and caching resources in the multi-layered 3D network. To this end, cloud-native and AI-native approaches provide flexibility, interoperability, and intelligence at different levels in 6G-SKY networks. Joint communication, sensing and computation, and safe AI capabilities are very vital to improve communication performance and ensure performance guarantees as well as to realize defined use cases, especially in urban air mobility and connectivity of ground users in rural areas.

From a 6G-SKY architecture perspective, communication scenarios of aerial platforms at different altitudes affect feasible technical solutions such as integrated access and backhaul, L2/L3 relaying, and different IP breakout points. As the 6G-SKY architecture will employ new communication solutions realizing new use cases for smart cities, smart transportation and digitalization of airspace, it will lead to new business opportunities contributing to economic sustainability. Furthermore, the 6G-SKY architecture will accelerate social acceptance of digital airspace and urban air mobility concepts which will improve the quality of life of citizens.

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7.3 Table

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7.5 Further reading

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Annexes: