D2.2: Use cases and KPIs

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Abstract	The three ETHER use cases have been described and their resulting KVIs, KPIs and requirements have been identified. This has been supplemented by a review of published material. From this analysis fifteen KPIs, thirty functional requirements, and eighteen non-functional requirements have been identified. Together these will provide direction for the work in the ETHER project.
Keywords	6G, NTN, Use cases, Requirements, KPIs, KVIs

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DISCLAIMER

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* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

OTHER: Software, technical diagram, algorithms, models, etc.

Executive summary

The three use cases being considered by ETHER have been described and their resulting KVIs, KPIs and requirements have been identified. This has been supplemented by a review of published material looking at the possibilities for 6G from major organisations around the world. These use cases are:

- **Use case 1:** Flexible payload-enabled service provisioning to semantics aware and delay-tolerant IoT applications;
- **Use case 2:** Unified RAN for direct handheld access;
- **Use case 3:** Air-space safety critical operations.

This deliverable is tasked with identifying the KVIs, KPIs, and requirements for each of its three use cases already identified above that are turn intended to showcase the research undertaken. The logic we follow for each use case is shown in Figure 0-1-1 below.

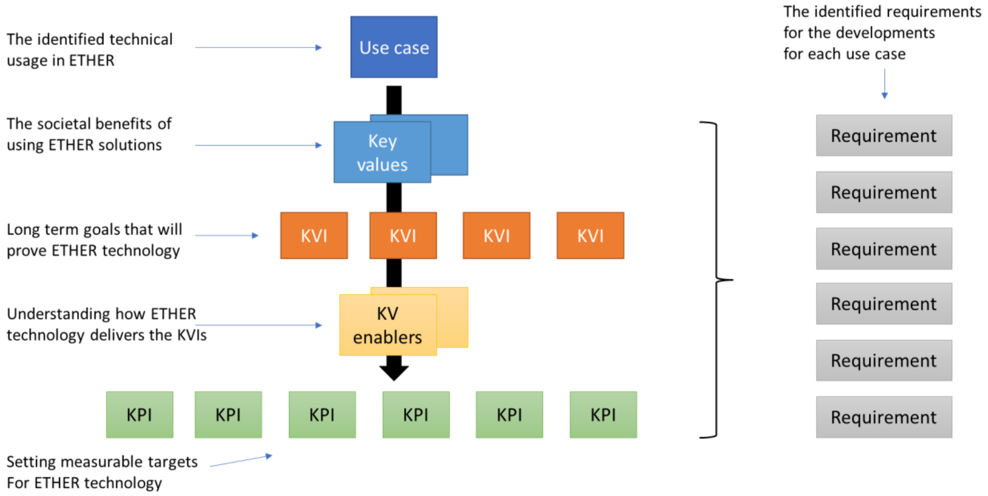

Figure 0-1-1: How ETHER derives the KVIs KPIs and requirements for each use case

Each use case will be analysed separately with the following flow:

- **Rationale:** why this use-case is needed and selected by ETHER including the links to project objectives and the research pillars.
- **Key values:** Main relevant societal benefits associated with the use-case.
- **Key value indicators:** The metrics that represent the long-term envisioned.
- **Key value enablers:** The key-enabling technologies needed to achieve the use-case.
- **Key performance indicators:** Measurable values to verify the efficacy of the proposed systems.
- **Requirements:** The requirements for each use case necessary to deliver a valid relevant and testable solution.

From this analysis fifteen KPIs, thirty functional requirements, and eighteen non-functional requirements have been identified. These provide direction for the work in the ETHER project.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5G	5th generation (mobile network)
5GCN	5G core network
5G PPP	5G Infrastructure Public Private Partnership
6G	6th generation (mobile network)
6GIA	6G Industry Association
AI	Artificial intelligence
AMF	Access management function
API	Application programming interface
ATM	Air traffic management
CNF	Containerised network function
CNS	Communication, navigation, and surveillance
CPU	Central processing unit
E2E	End-to-end
EC	European Commission
ESA	European Space Agency
FPGA	Field programmable gate array
GEO	Geostationary earth orbit
gNB	gNodeB
GSMA	GSM Association
GSO	Geostationary orbit
GSOA	Global Satellite Operator Association
HAPS	High altitude platform system
HH	Horizontal handover
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
ITU	International Telecommunication Union
ITU-R	ITU – radiocommunication sector
ITU-T	ITU – telecommunication standardisation sector
KPI	Key performance indicator
KVI	Key value indicator
LEO	Low earth orbit
MANO	Management and orchestration
MAR	Mobile autonomous reporting
ML	Machine learning
MPC	Model predictive control
NB-IoT	Narrow band IoT
NFV	Network function virtualisation
NGMN	Next Generation Mobile Networks (Alliance)
NGSO	Non-geostationary orbit
NICT	National Institute of Information and Communications Technology
NTN	Non-terrestrial network

OFDM	Orthogonal frequency-division multiplexing
OSM	Open source MANO
OTFS	Orthogonal time frequency space
QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RCP	Required communication performance
RF	Radio frequency
S&F	Store and forward
SDG	Sustainable development goal
SDN	Software defined network
SDO	Standards developing organisation
SFC	Service function chaining
SoC	System on a chip
SotA	State of the art
TCO	Total cost of ownership
TN	Terrestrial network
TRL	Technology readiness level
TSDSI	Telecommunications Standards Development Society, India
TSN	Time sensitive network
UE	User equipment
UN	United Nations
VH	Vertical handover
VNF	Virtualised network function
XR	Extended reality

1 BACKGROUND

1.1 PROJECT OBJECTIVES AND PLANNED INNOVATIONS

1.1.1 Objectives

In the ETHER proposal [1] the following five project objectives were identified:

1. Provide solutions for a unified and sustainable radio access network (RAN) for the integrated terrestrial network (TN) and non-terrestrial network (NTN);
2. Provide an AI-based framework for the self-evolving network slicing management and orchestration of the integrated network, automatically adjusting its management policies and allocated resources based on stimuli corresponding to unknown environments and situations;
3. Architect a viable, highly energy- and cost-efficient, flexible integrated terrestrial and non-terrestrial 6G network offering seamless and continuous connectivity.
4. Demonstrate the effectiveness of ETHER solutions by experimentation activities that target practical applications;
5. Identify the key benefits that will drive the investment in the integration of non-terrestrial with terrestrial networks.

1.1.2 Planned innovations

The proposal also stated that:

> "*ETHER is going to provide a framework for the terrestrial/non-terrestrial network ecosystem that involves an efficient and zero-touch resource management, provides solution for key RAN challenges, and identifies the business opportunities for potential stakeholders. ETHER relies on the following innovations:*
>
> - *Unified RAN advancements that enable broadband connectivity from every corner of the world even with handheld devices (**Pillar I**).*
> - *Intelligent management of the 3D network resources for meeting predefined KPIs, allowing the network to self-adapt to rapidly evolving traffic conditions and situations on the ground without human intervention (**Pillar II**).*
> - *A distributed 3D computing and caching medium enabling the reduction of response delays by alleviating congestions towards cloud data centre (**Pillar III**).*"

These three pillars mentioned anchor the project's planned innovations and a bit more detail was added.

Pillar I: *Enabling unified RAN performance through efficient handheld device antenna design at the Ka band together with distributed beamforming from LEO satellite swarms for direct access, unified waveform development, and horizontal handovers (HHs)/vertical handovers (VHs) among the different radio access technologies (RATs), so that the users experience service continuity.*

Pillar II: *Software-based multi-layered integrated network optimisation in a zero-touch fashion by advanced data-driven algorithms that rely on gathering a massive amount of data generated by terrestrial, aerial and space platforms. This pillar includes also the enabling technologies for the network softwarisation, such as the network function virtualization (NFV) and software-defined payloads for aerial/space platforms, referred to as flexible payloads in the rest of the document.*

Pillar III: *Multi-layered distributed edge-computing and caching for offloading computational tasks related to a massive amount of data to the edge and thus close to where the data is produced. This is the only viable way to achieve in such a highly heterogeneous, large scale and dynamic network the latencies envisioned in forthcoming 6G networks.*

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1.2 IDENTIFICATION OF PUBLISHED 5G AND 6G USE CASES

This activity starts with this web-based survey identifying for published 5G and 6G uses cases, recommendations, and architectural guidelines to put the project work in context of the wider evolving ecosystem. Preference was given to groups of organisations rather than by one individual organisation to seek clarity on the direction of travel as the telecommunications world moves through the 3GPP releases towards 6G.

Table 1-1 below lists the main organisations (in alphabetical order) and the most relevant documents that were found.

Table 1-1: Published documents with beyond 5G and 6G use cases, etc.

Organisation	Documents	Issued	Ref
5G Americas	Becoming 5G Advanced the 3GPP 2025 roadmap	Dec-22	[2]
5G PPP	European vision for the 6G network ecosystem	07-Jun-21	[3]
5G PPP	The 6G architecture landscape V6.0	6-Feb-23	[4]
5G PPP	Whitepaper beyond 5G/6G KPIs and target values	Jun-22	[5]
5G PPP	KPIs measurement tools	Mar-23	[6]
6GIA/SNS	What societal values will 6G address?	31-May-22	[7]
6G Flagship	White paper on broadband connectivity in 6G	Jun-22	[8]
6G Flagship	White paper on 6G drivers and the UN SDGs	Jun-22	[9]
CAICT	White paper on 6G vision and candidate technologies		[10]
EC	Hexa-X D1.1 – 6G vision, use cases and key societal values	26-Feb-21	[11]
EC	Hexa-X D1.2 – Expanded 6G vision, use cases and societal values	30-Apr-21	[12]
EC	Hexa-X D1.3 – Targets and requirements for 6G – initial E2E architecture	28-Feb-22	[13]
EC	Hexa-X D5.1 – Initial 6G Architectural components and enablers	02-Mar-22	[14]
EC	Hexa-X D5.2 – Analysis of 6G architectural enablers' applicability and initial technological solutions	30-Oct-22	[15]

Organisation	Documents	Issued	Ref
ESA	EAGER project – Architectures, services, and technologies towards 6G non-terrestrial networks	Feb-23	[16]
GSMA	Nothing identified	-	-
GSOA	Satellite communications and their role in enabling 6G	24-Oct-22	[17]
IEEE	International network generations roadmap	Annually, 2022, 2023	[18]
ITU	Recommendation ITU-R M.2083-0 IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond	Sep-15	[19]
ITU	Report ITU-R M.2516-0 – Future technology trends of terrestrial international mobile telecommunications systems towards 2030 and beyond	Nov-22	[20]
ITU	Recommendation ITU-T Y.3200 Fixed, mobile and satellite convergence – Requirements for IMT-2020 networks and beyond	13-Feb-22	[21]
ITU	Recommendation ITU-T Y.3201 Fixed, mobile and satellite convergence – Framework for IMT-2020 networks and beyond	13-Jan-23	[22]
ITU	Recommendation ITU-T Y.3202 Fixed, mobile and satellite convergence – Mobility management for IMT-2020 networks and beyond	14-May-23	[23]
ITU	Recommendation ITU-T Y.3203 Fixed, mobile and satellite convergence – Connection management for IMT-2020 networks and beyond	14-May-23	[24]
NetworldEurope	Strategic Research and Innovation Agenda 2022	13 Dec 2022	[25]
NetworldEurope	SRIA Technical Annex	Annually, 2022	[26]
Next G Alliance	Roadmap to 6G	Feb-22	[27]
Next G Alliance	6G Applications and use cases	2022	[28]
NGMN	6G Use cases and analysis	22-Feb-22	[29]
NGMN	6G Drivers and vision	19-Apr-21	[30]

Organisation	Documents	Issued	Ref
NGMN	6G Requirements and design considerations	14-Feb-23	[31]
NGMN	6G position statement – An operator view	6-Sep-23	[32]
NICT	Beyond 5G/6G white paper v2.0	Jun-22	[33]
One6G	White paper, 6G vertical use cases	Jun-22	[34]
One6G	White paper, 6G technology overview – second edition	Nov-22	[35]
SK Telecom	SK Telecom 6G white paper	Aug-23	[36]
TSDSI	6G use cases and enabling technologies	Sep-22	[37]

Each document is reviewed for relevance to ETHER in its use case to KPIs and requirements analysis. A summary of each of these reviews is in Appendix A – Review of published documents starting on page 48. It is encouraging for the unification of NTN and TN in 6G to find that in eighteen out of the twenty-one documents reviewed mentioned NTNs.

Following the reviews one or more key findings are given. These will be linked where appropriate to the following use case analyses. The work in these third-party documents will be compared with the use case analyses as part of the comparison work in chapter 5.

1.3 PROCESS FOLLOWED

1.3.1 Background

In the ETHER proposal [38] three research pillars are described, which shape the project objectives and the key value indicators (KVIs), as illustrated in Figure 1-1 . It does not mention any intermediate steps between use cases and key performance indicators (KPIs).

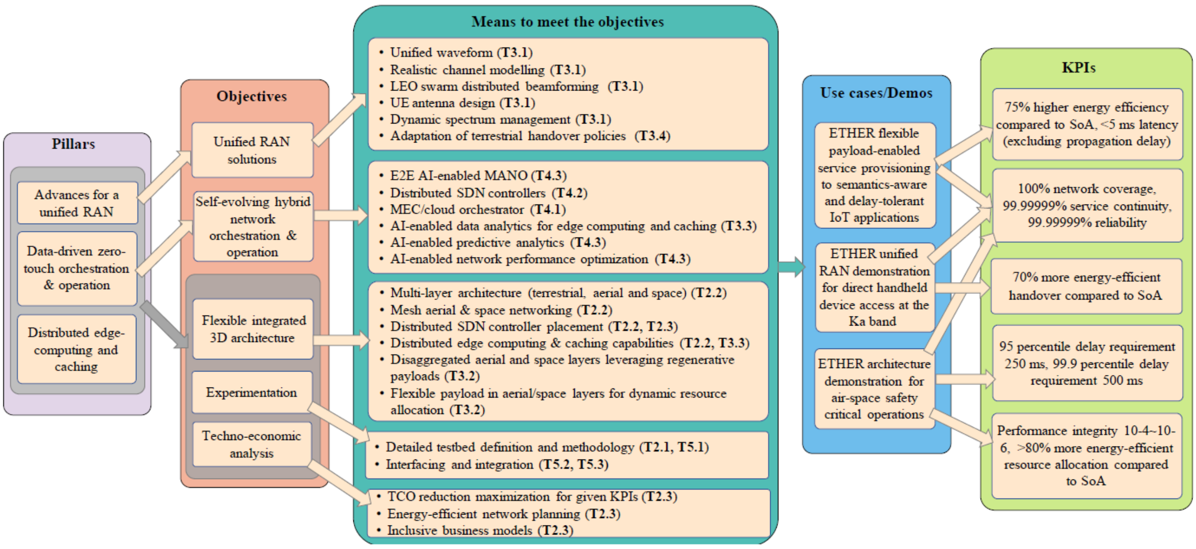

Figure 1-1: ETHER objectives and vision [38]

It is worth noting that "means to meet the objectives" may well closely relate to the key value enablers described below in one very relevant document [7], issued by 6GIA, that provides a clear description of how KVIs are related to use case cases and KPIs in a diagram reproduced in Figure 1-2 .

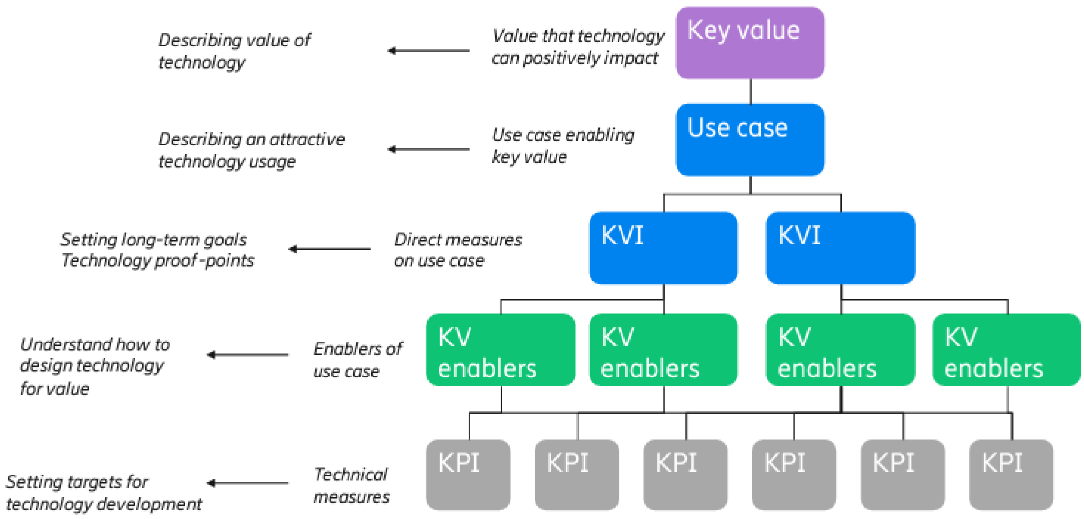

Figure 1-2: Overview of KVI related concepts [7]

In the Hexa-X project that is "*A flagship for 6G vision*" from the EC Horizons program, and in particular described in [12] and [13], they start with their use cases and then derive the KVIs and KPIs.

1.3.2 ETHER process

This deliverable is tasked with identifying the KVIs, KPIs, and requirements for each of the proposed three use cases already identified above, which are turn intended to showcase the undertaken research. The logic, followed for each use case, is shown in Figure 1-3 below.

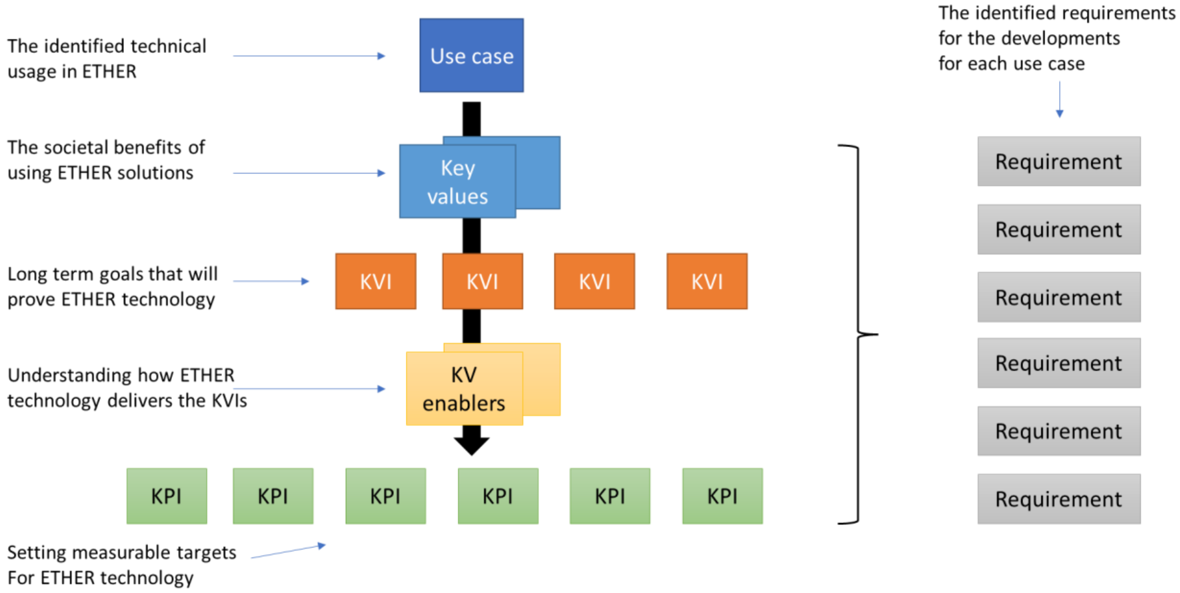

Figure 1-3: How ETHER derives the KVIs KPIs and requirements for each use case

Each use case will be analysed separately with the following flow:

- **Rationale:** Details why this use-case is needed and selected by ETHER including the links to our project objectives and to the research pillars;
- **Key values:** Main relevant societal benefits associated with the use-case;
- **Key value indicators:** The metrics that represent the long-term envisioned performance noting that a KVI is an indicator of social success/achievement;
- **Key value enablers:** The key-enabling technologies needed to achieve the use-case;
- **Key performance indicators:** The measurable target values by which one can verify the efficacy of the proposed systems;
- **Requirements:** The requirements for each use case necessary to deliver a valid relevant and testable solution.

Once the analysis for each use case has been completed, the KPIs and requirements will be compared, and a consolidated list is created.

The following numbering will be used during the use case analyses:

- **Requirements:** ETH-REQ-UCn-tt-xxx

Where n is 1, 2 or 3 for the use case number, and x is a sequential integer for each category and use case. In use case 2 and 3 tt is FN for functional requirements whereas it is NF for non-functional requirements. In use case 1 tt refers to the specific aspects; so FP = Flexible Payload & service orchestration, DT = Delay-Tolerant IoT, and SE = Semantics-aware information handling. In addition, a few general requirements are identified that are indicated by GEN.

A similar format is used for KPIs: ETH-KPI-Ucn-xxx.

2 USE CASE 1: FLEXIBLE PAYLOAD-ENABLED SERVICE PROVISIONING TO SEMANTICS AWARE AND DELAY-TOLERANT IOT APPLICATIONS

2.1 DESCRIPTION

The provision of a delay-tolerant Internet of Things (IoT) service, based on a 3GPP-compatible Store & Forward (S&F)-enabled NB-IoT deployment in a satellite system, will be achieved by means of the Flexible Payload (Objective 3, and Innovation Technology T-5). This payload will have a crucial role in the execution of the demonstration. Specifically, the payload will allow to deploy this NB-IoT service onto the different satellites, over a target region, at a given moment in time. The management will be orchestrated by a ground-based Management and Orchestration (MANO) that will instruct the satellites to activate and deactivate services in a coordinated manner, exchanging status and context with satellites to come.

To achieve the desired architecture, development of different capabilities will focus in three main scopes: a) management of infrastructure resources from different domains such as registration of cloud/edge and RAN resources, b) slice management capability through which reserved resources per slice are registered and configured, where each slice is composed of cloud/edge compute chunks, RAN chunks, and 5G Core Network (5GCN)/cloud/edge network chunks, and c) management of network services including service instantiation/termination/migration, service update, and service recovery. Additionally, along NB-IoT-based applications, other IoT-based and non-IoT-based applications will be deployed in the flexible payload to demonstrate the possibility to execute them simultaneously. With this execution, it is expected to verify that the design and development of the flexible payload is capable to autonomously manage internal software-based payloads and propagate their status among the satellites to ensure service continuity.

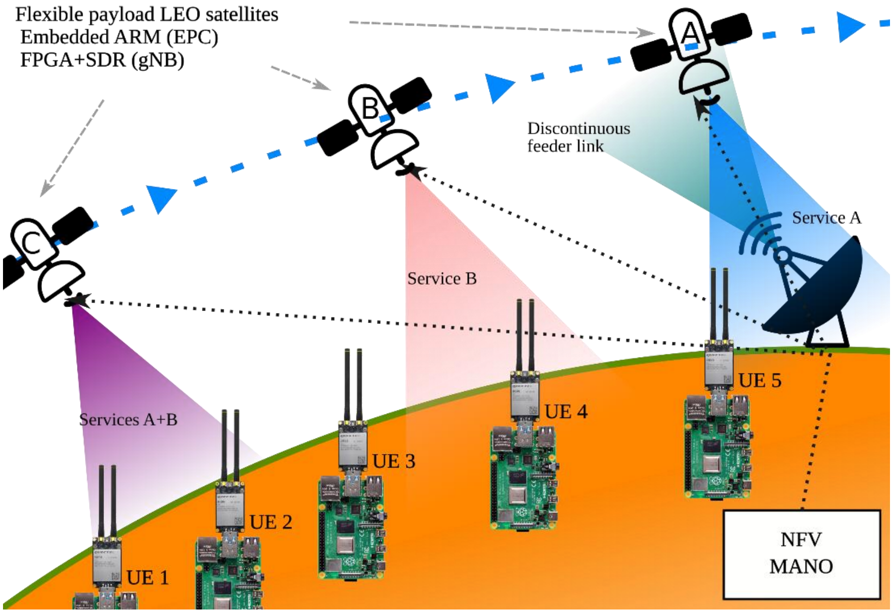

Figure 2-1: Use case 1, delay-tolerant IoT services

In Figure 2-1 a low-density constellation of low earth orbit (LEO) satellites is shown that provides global coverage to user equipment (UE) devices on the ground. The network function virtualisation (NFV) MANO coordinates the flexible payloads at the satellites to operate the right services at the right time to provide UEs with connectivity. Semantics-aware information handling will work to create the right amount of data and transmit the right content to the right place at the right time.

The small density constellation of LEO satellites has a smaller deployment cost, but it introduces discontinuities on the feeder and service link. Provision of network coverage from LEO satellites with service and feeder link discontinuity will bring global coverage to delay-tolerant massive machine type communications (mMTC) applications. Furthermore, providing service with multiple technologies by means of flexible payload allows for a higher number and variety of supported devices and applications, which allows for a bigger market impact and reduces vendor and technology lock-in.

Use case 1 is composed of three different elements:

- Delay-tolerant IoT applications as the service;
- Flexible payload and service orchestration as the 1st enabler; and
- Semantics-aware information handling solutions as the 2nd enabler.

This pattern is followed in each of the subsections looking at this use case.

2.1.1 Delay-tolerant IoT applications

ETHER will contribute to delay tolerant IoT applications by providing them with cost-efficient connectivity, which will pave the way for the widespread adoption of IoT solutions. Delay-tolerant IoT applications, which do not rely on low latency, can benefit from low-density LEO satellite constellations that are offer more cost-effective IoT services than mega constellations or geostationary orbit (GEO) satellites. This reduces in turn the connectivity costs and enable IoT use cases to scale globally.

2.1.2 Flexible payload and service orchestration

ETHER will contribute to improving the following aspects by using the flexible payload concept combined with service orchestration:

1. Edge computing;
2. Repurposing in-orbit infrastructure;
3. Federated satellite systems;
4. Reconfiguration of in-orbit infrastructure;
5. Service continuity;
6. Unified network management.

The contribution details are described (explained or discussed) in the following sections.

2.1.3 Semantics-aware information handling solutions

ETHER will contribute to IoT networks through the semantic-aware approach aimed at generating the right amount of data and transmitting the right content to the right place at the right time, considering the available resources. To achieve this, semantic attributes are employed and optimised as the key performance metrics. In particular, semantics refers to the importance and relevance, rather than the meaning of information. More specifically, leveraging semantics in NTNs will allow for the generation and transmission of only a small fraction of data without affecting the conveyed information, which leads to improved energy efficiency and lower latency.

2.2 RATIONALE

2.2.1 Delay-tolerant IoT applications as the service of interest

The ETHER project has identified delay tolerant IoT applications as an important use case with its use case 1 that can be served by utilising low-density LEO constellations and cost-efficient connectivity, which have been a barrier for supporting massive IoT applications. Examples of delay tolerant IoT application can be found in **Error! Reference source not found.**. Note that t he maximum supported delay is tied to the IoT application, and the values provided are refences.

Table 2-1: Delay Tolerant IoT Application examples with supported delay.

Delay Tolerant IoT Application	Description	Supported delay	Notes
Smart Agriculture	Monitoring soil moisture, weather conditions, and crop growth using IoT sensors.	Several hours to a day. Periodic updates.	Soil moisture data can be collected and transmitted once a day, as these conditions do not change rapidly
Livestock Managment	Monitoring of livestock, including location and health indicators.	Several hours to a day.	
Enviromental Monitoring	Tracking air quality, water quality, or wildlife using sensors in remote areas	Several hours to days.	Enviromental changes occur over longer periods
Asset Tracking	Tracking the location and condition of goods during transportation.	Several hours.	Real-time tracking is not always needed. Locations can be saved and shared once every several hours.
Structural Health Monitoring	Monitoring the integrity of buildings, bridges, and other infrastructure.	Several hours to days.	Structural changes typically occur over long periods.
Smart Waste Management	Monitoring fill levels of waste bins.	Several hours to a day.	
Energy and Water Usage Monitoring in Smart Cities	Monitoring and analysing usage patterns for efficient resource management.	Several hours to a day.	

However, employing a low-density LEO satellite constellation can generate discontinuities on the service link when no satellite is in communication with the UE. Furthermore, the feeder link connecting satellites and ground are only available at a few locations, which brings a series of challenges requiring the adoption of regenerative payload architecture and the usage of store and forward mechanism (not only for the data layer, but also for the control plane, therefore standard 3GPP procedures will need some adaptations).

To enable this service, two main key architectural challenges should be addressed as part of ETHER contributions:

1. Enabling discontinuous NB-IoT backhauling so that a satellite can provide service even when not attached to the ground station via the feeder link;
2. Providing standard 3GPP interfaces so that multiple service providers can use the same LEO constellation to extend their service footprint (i.e., roaming).

Other challenges that should be also addressed by ETHER contributions are:

1. Mobility management;
2. Dynamic organisation of tracking areas;
3. Broadcasting of ephemerides to end devices to assist them in using network and power resources efficiently.

2.2.2 Flexible payload and service orchestration as the first enabler of Use Case 1

A federated satellite system is a communication network where multiple satellite nodes cooperate and work together to provide different services. In this kind of system, satellite nodes are interconnected and can share resources and information with each other. This allows for improved efficiency and flexibility in deploying and managing applications and services within the satellite network. The federation enables coordination and collaboration among the satellite nodes, enhancing the system's overall performance and reliability. Resource optimisation is a crucial aspect of satellite systems due to the need for efficient allocation and management of limited resources such as bandwidth, power, and processing capabilities. Optimising these resources is vital for ensuring high-quality services and maximize the utilisation of available resources, which is essential for providing reliable and efficient communication services.

Reconfiguration of in-orbit infrastructure refers to the process of altering or adjustments to the existing satellite network and its components that are already deployed in space. This process may involve modifying the hardware or software configurations of the satellites, as well as adjusting the network architecture and resource allocation. The goal of such reconfiguration is to enhance the performance, efficiency, and functionality of the satellite networks, ensuring it to adapt to changing conditions and requirements in real-time.

Supporting edge services, the reconfiguration of in-orbit infrastructure leverages the capabilities of satellite networks integrated with terrestrial infrastructures. Such integration is crucial for the deployment of edge services in remote and underserved areas, thereby broadening connectivity. In-orbit infrastructure, through the dynamic management of satellite resources enabled by virtualisation and software-defined orchestration, can adapt to conditions changes and demands in real-time. This collaborative approach ensures efficient resource use, the provision of low-latency services, and the optimisation of content distribution for edge services.

The NewSpace concept is opening new business opportunities using primarily LEO satellites to deploy services. Global coverage is achieved using satellite constellations; however, a primary concern is optimising the use of satellite resources, which are limited for each satellite and consumed differently depending on the geographic area and service demands. Reconfigurable payloads can address the resource sharing challenge and provide the flexibility to launch multiple services from the same platform and reuse already in-orbit infrastructures, thereby maximising mission revenues.

Regarding service continuity, ensuring uninterrupted access to services for UEs across terrestrial and non-terrestrial systems is a challenge. This can be addressed by using the software-defined networking (SDN) paradigm. In essence, SDN controllers facilitate the dynamic management and routing of traffic between network elements under their control. This routing can comply with quality of service (QoS) principles and path optimisation; or can be used to mitigate disconnection issues. The integration of SDN controller in the ETHER MANO architecture ensures the management of traffic demands in geographically distributed areas with multiple network access points, such as ground layer 5G base stations (gNodeBs or gNBs) and satellites in the space layer. This integration permits seamless access to network services deployed across both layers.

2.2.3 Semantics-aware information handling solutions as the 2nd enabler of use Case 1

Semantic-aware solutions have been incorporated as a part of use case 1 within ETHER, contributing to the realisation of its goals. Since we are dealing with delay-tolerant applications, the process of generation of information can be adjusted to reduce or even eliminate the amount of information that is generated during the periods without or with limited connectivity. This will also have an impact on the energy consumed by the end devices that can be associated with a more energy efficient operation. In addition, packet management techniques can prioritize important information when the connectivity is restored, resulting in (leading to) more efficient status updating systems. These information handling techniques are applicable to both data and control planes.

2.3 KEY VALUES

The key values identified when considering each element of use case 1 are:

2.3.1 Delay-tolerant IoT applications

ETHER will add the following capabilities to low-density LEO satellite constellations to support delay tolerant IoT application:

- Support of intermittent connectivity on the service and feeder link by using S&F mechanism on the control and user plane using standard 3GPP procedures;
- Support for HHs between LEO satellites to avoid multiple registrations of the same device to the network;
- Support of deployment over low-density LEO satellites constellation providing standard 3GPP interfaces to allow an extension of service footprint;
- Provide an efficient use of power resources on devices.

2.3.2 Flexible payload and service orchestration

Flexibility at payload level allows satellite platforms to adapt to on-demand services and geographic areas, offering non-mission specific satellites. As LEO designs often utilize commercial of-the-shelf electronics based on Field Programmable Gate Array (FPGA), the hardware can be used again, and development and testing time as well as design cost can be reduced. Moreover, satellites can be recycled if mission is cancelled or changed. As services can be modified, the concept of resource sharing emerges, enabling the allocation of already deployed, on-air resource to operators and ground stations.

Universal access to services for UEs is essential in both satellite and terrestrial environments, regardless of the satellite's visibility zone and the UE's location. The goal is to eliminate coverage dead zones in geographic areas where services have been inaccessible through traditional network operator's base stations.

Deploying a satellite cluster in space offers numerous advantages. It enables the efficient use of the underutilised hardware resources such as in-orbit storage, computing, and networking. This transformation turns individual satellites into a cooperative cluster with the capabilities of a highly efficient distributed computing platform. The cluster's dynamic nature is key, allowing the seamless integration of new satellites as they enter the designated service area. This capability not only strengthens the infrastructure's capabilities and coverage, but also ensures uninterrupted service availability and adaptability.

The collaborative synergy among the cluster nodes empowers them to handle larger, more complex tasks by pooling their collective resources and capabilities. Such cooperation highlights the scalability of the cluster and improves its operational efficiency. Furthermore, the incorporation of service function chaining (SFC)-based NFV technology provides the capability to deliver an array of diverse services and applications across the satellite constellation, fostering a dynamic, adaptable, and resource-rich space-based infrastructure.

The following key values are provided for the flexible payload and service orchestration deployment:

1. Satellite cost reduction by reusing electronics or repurposing a complete satellite;
2. Satellite resource sharing concept (offer already deployed on-air resource to operators and ground stations);
3. Distributed SFC over satellite constellations (interconnected nodes for complex services);
4. Cooperative edge computing in the space segment (multi node clusters capable of bigger tasks);
5. Scale services horizontally or vertically (allocating more resources in the same node or deploy more instances in different nodes).

2.3.3 Semantics-aware information handling solutions

ETHER will employ data analytics, semantic-aware metrics, and proactive caching to enhance the information handling solutions, with the capability to improve:

1. End-to-end (E2E) Latency;
2. Energy efficiency;
3. Accuracy;
4. Timely throughput.

2.4 KEY VALUE INDICATORS

The key values introduced by the realisation of use case 1 are described in the following sections:

The main key value indicators are listed below for satellite systems, which could be observed and measured to obtain real status of the deployment scenarios:

- Novel payloads, that are adaptable to services and geographic areas, provide global coverage in LEO and facilitate the provision of new applications;
- Improved network services orchestration in satellites and dynamic programmability of links to ensure service reliability;

- The ability to automatically control service coordination through configuration files, which describe the desired state of the service and efficiently deploy or withdraw services from the ground stations;
- Monitoring of resource usage by deployed services, with adjustments made to meet QoS requirements and to adapt resource allocation for consistent QoS;
- Ensuring global coverage with a limited number of satellites, while maintaining service continuity during periods of discontinuous satellite coverage by enabling seamless handover from one satellite coverage window to another.

The repurposing of in-orbit infrastructure, as measured by the number of recovered infrastructures, aids in reducing debris, reflected by the number of de-orbited satellites. From the point of view of the delay-tolerant application, the key value indicators are the following:

1. Coverage opportunities (number and duration of each contact);
2. Node maximum lifetime;
3. Device and solution cost;
4. Horizontal handover support;
5. Support for S&F;
6. Security support – E2E security;
7. Standard-based solution – compliant with current 3GPP standards;
8. Scalability/flexibility.

From the point of view of the semantics-aware information solution, the key value indicators are the following:

1. Age of information constraints;
2. Achievable timely throughput
3. Required accuracy for distributed machine learning (ML) scenarios;
4. Sampling frequency;
5. Content popularity;
6. Reduction in generated, stored, transmitted, and processed data without affecting the conveyed information.

2.5 KEY VALUE ENABLERS

The key-enabling technologies to deliver use-case 1 have been identified as:

- **Flexible payload:** satellite services are typically mission-specific, but in LEO operators need to adapt services to geographic area and may necessitate updates during the mission to introduce new features such as new standards and protocols. Typical hardware is fixed, and number of deployable services is limited to platform capacity. More services imply more electronics, increased mission preparation time and higher costs. A flexible payload will allow the use of cost-effective system-on-chip (SoC) integrated circuits based on FPGA to design a software defined radio (SDR) platform that deploys software and hardware-based services across a wide range of Radio Frequency (RF) communication bands through their high-speed transceivers. Additionally, as commercial FPGAs integrate high computing processors with reprogrammable logic, this combination enables hardware reconfiguration (Flexibility Level 1–Logic Cells reconfiguration), software virtualisation using containerisation techniques (Flexibility Level 2–Container Framework) and remote service orchestration (Flexibility Level 3–Orchestration Framework).

- **Network management**: dynamically managing communication links is a current challenge for network operators, especially with the integration of satellite, aerial and terrestrial networks, commonly referred to as 3D networks, where network programmability complexity increases. ETHER MANO seeks to maintain active links while preserving user quality of experience (QoE) for users. It integrates distributed virtualised services and networks orchestration systems. In this light, SDN is a pivotal component that, together with NFV MANO, ensures proper orchestration of communication links within these 3D networks.
- **Orchestrator**: the orchestration of satellite clusters significantly benefits from the combination of Open-Source MANO (OSM) and Kubernetes, ensuring seamless deployment and management of both virtual and physical resources, while tackling the challenges of satellite mobility. OSM is a robust orchestration framework, which excels at deploying and managing Virtualised Network Functions (VNFs) and Containerised Network Functions (CNFs), automating tasks such as provisioning, scaling, monitoring, and lifecycle management. In satellite cluster orchestration, OSM takes the lead in efficiently deploying VNFs and CNFs across satellites the cluster's satellites, managing resource allocation, scheduling, and maintaining the workload's overall health and availability. On the other hand, Kubernetes, an open-source container orchestration platform, while primarily focused on containerised applications administration, also addresses the unique demands of satellite networks. It manages the physical and virtual resources and network discontinuities resulting from satellite mobility. Particularly, it excels at tasks such as container scheduling, load balancing, and fault tolerance, which can be leveraged to address connectivity disruptions caused by satellite movements.
- **Horizontal handover policies:** managing the user authentication in a multi-satellite constellation presents a series of challenges, as the user context must be distributed in all satellites to allow the UE to communicate to any satellite in the constellation. The horizontal handover policies reduce the problem of double authentication on the same constellation, as data is transferred between cells (satellites) within the same access core network, reducing inefficiencies and delays which can disrupt seamless connectivity, ensuring a more consistent and rapid transition between cells.
- **Semantics-aware information handling solutions:** Optimising the quantity of generated, stored, transmitted, and processed data within an E2E IoT network is a formidable challenge, particularly when dealing with intermittent links and limited energy resources. ETHER tackles these challenges by leveraging data analytics, edge computing and proactive caching, employing semantic-aware performance metrics, and taking a holistic approach to the entire communication network, from data sampling to utilisation.

2.6 KEY PERFORMANCE INDICATORS

The targeted key performance indicators of use case 1 are the following:

- 75% higher energy efficiency compared to the state of the art (SotA);
- 100% network coverage (outdoors).

Table 2-2: KPIs for use case 1

Identifier	KPI	Description
ETH-KPI-UC1-01	Energy Efficiency	>75% compared to SotA
ETH-KPI-UC1-02	Network coverage	100% network coverage

2.7 REQUIREMENTS – FUNCTIONAL AND NON-FUNCTIONAL

The functional requirements for use case 1 are the following:

- Manage and deploy FPGA resources dynamically and autonomously, considering specific context. Control available resources and their percentage of use;
- Ensure that services are deployed correctly using virtualisation techniques and containers;
- Ensure proper multiplexing for resource sharing, considering interfaces universal asynchronous receiver/transmitter (UART), Ethernet) and other hardware resources (memory, buffers, analogue-to-digital converters);
- Agreement to establish a contact at a particular time. Contacts are not scheduled but occur unexpectedly. Predicted contacts do not have fixed schedule but are predictions of likely contact times and durations based on a history of previous contacts or other information (satellite ephemerides) and ML in ETHER. Device messages arrive at destination with support for vertical and HH, congestion and flow control, and message retransmissions;
- Support of a low-density LEO constellation with service link and feeder link discontinuity.
- Support for S&F on low-density LEO constellation, to solve connection discontinuity and support of S&F over vertical and HHs according to ML in ETHER;
- Dynamic organisation of tracking areas, or broadcasting of ephemerides to end devices to assist them in using network and power resources efficiently. Influence the entire information chain from the generation, encoding, transmission, and reception of the information to its utilisation for achieving a certain goal, such as datasets (or partial datasets) to train an ML algorithm. Identify criteria for reusable traffic to effectively cache the freshest and most valuable information proactively.

The non-functional requirements for use case 1 are the following:

- Extract metrics of the system, when enabled, to monitor different system parameters: power consumption, Central Processor Unit (CPU), disk and memory usage;
- Support for high latency at low data rates for delay-tolerant IoT application;
- Handle mobile autonomous reporting (MAR) exception reports (notify sporadic events) and MAR periodic reporting (regular transmission);
- Support multi-radio applications based in NB-IoT using ML in ETHER and orchestrated by the MANO.

The requirements above were reviewed by the project team, which results in the following consolidated requirements list for use case 1.

Table 2-3: Consolidated use case 1 requirements

Identifier	FN or NF	Requirement	Description
ETH-REQ-UC1-FP-01	FN	Payload FPGA resources management	Manage and deploy in a dynamic and autonomous way FPGA resources considering specific context.
ETH-REQ-UC1-FP-02	FN	Payload FPGA resources availability	Control available resources and its percentage of use.
ETH-REQ-UC1-FP-03	FN	Payload FPGA services deployment	Ensure that services are deployed correctly using virtualisation techniques plus containers.
ETH-REQ-UC1-FP-04	FN	Payload FPGA resources sharing	Ensure proper multiplexing for resource sharing, considering interfaces (UART, ethernet) and other hardware resources (memory, buffers, analogue-to-digital converters).
ETH-REQ-UC1-FP-05	NF	Payload system performance metrics	Extract metrics of the system when enabled to monitor different parameters of the system: power consumption, CPU, disk and memory usage.
ETH-REQ-UC1-DT-01	FN	Intermittent – scheduled contacts	Agreement to establish a contact at a particular time.
ETH-REQ-UC1-DT-02	FN	Intermittent – opportunistic contacts	Contacts are not scheduled but present themselves unexpectedly.
ETH-REQ-UC1-DT-03	FN	Intermittent – predicted contacts	Predicted contacts have no fixed schedule, but instead are predictions of likely contact times and durations based on a history of previous observed contacts or some other information (satellite ephemerides) and ML in ETHER.
ETH-REQ-UC1-DT-04	FN	Congestion and flow control	Device messages arrive at destination, with support for vertical and HH, f congestion and flow control, message retransmissions.
ETH-REQ-UC1-DT-05	NF	High latency, low data rate	Support for high latency at low data rates for delay-tolerant IoT applications.
ETH-REQ-UC1-DT-06	FN	Connection discontinuity	Support of a low-density LEO constellation with service link and feeder link discontinuity.
ETH-REQ-UC1-DT-07	FN	Store and forward	Support for store and forward (S&F) on low density LEO constellation, to solve connection discontinuity, and support of S&F over vertical and HHs according to ML in ETHER.
ETH-REQ-UC1-DT-08	NF	Traffic model MAR	Handle MAR exception reports (notify sporadic events) and MAR periodic reporting (regular transmission).
ETH-REQ-UC1-DT-09	FN	Mobility management	Dynamic organisation of tracking areas, or broadcasting of ephemerides to end devices to assist them in using network and power resources efficiently.
ETH-REQ-UC1-DT-10	NF	Support for different services	Support of multi-radio applications based in NB-IoT using ML in ETHER and orchestrated by the MANO.
ETH-REQ-UC1-SE-01	FN	Sample processing	Influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the

Identifier	FN or NF	Requirement	Description
			utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-02	FN	Joint sample and transmit	Influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-03	FN	Support for E2E information handling beyond the sample and transmit	Influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-04	FN	Content caching	Need to find the criteria for reusable traffic to effectively cache the freshest and also valuable information proactively.

3 USE CASE 2: UNIFIED RAN FOR DIRECT HANDHELD DEVICE ACCESS

3.1 DESCRIPTION

This second use case “Unified RAN for direct handheld device access” is illustrated below in Figure 3-1.

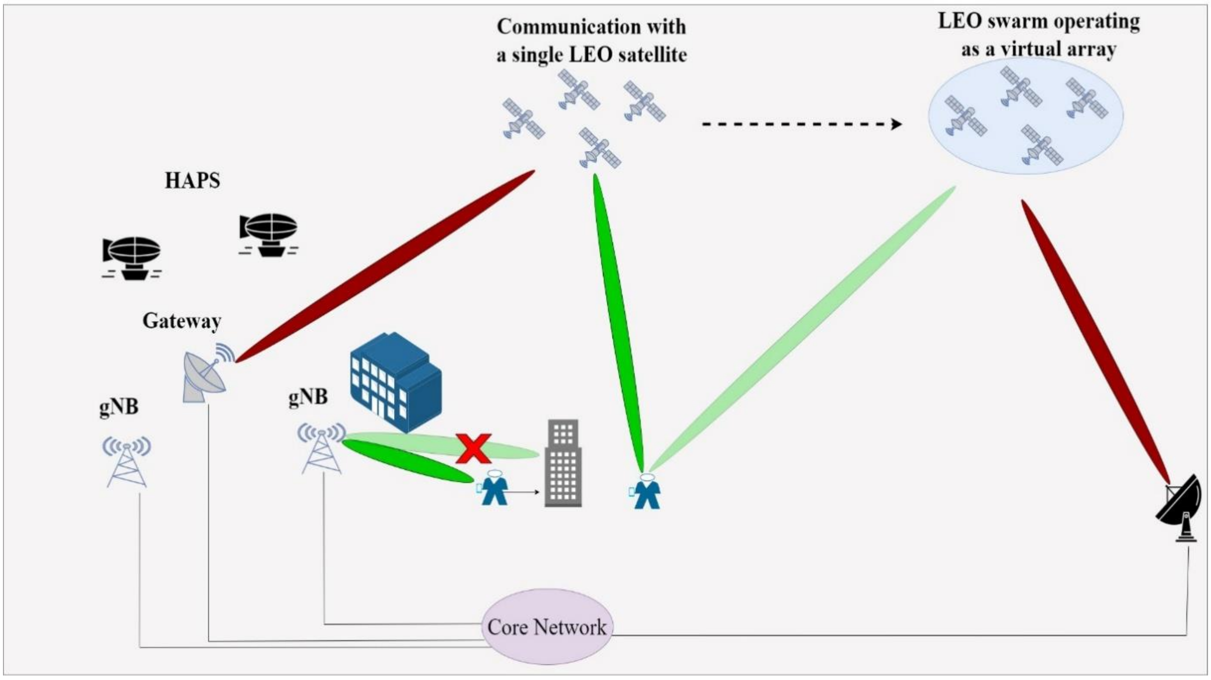

Figure 3-1: Use case 2: Unified RAN for direct handheld device access at the Ka band

For example, one can consider a mobile handheld device is initially connected to a terrestrial site (gNB). As the device is moving, the received signal from the terrestrial site starts deteriorating due to an obstacle in its vicinity. Based on reported measurements from the handheld device about the signal strength from other terrestrial sites and from non-terrestrial platforms, such as LEO satellites, a handover process will be triggered through intelligent algorithms (to be described in ETHER D3.1 and D3.2) that target the maximisation of the energy efficiency subject to constraints related to time availability, flow conservation, power, and capacity constraints. In the case of connecting to a non-terrestrial platform, the ability to choose by ML means whether to deploy OFDM or OTFS waveforms (orthogonal frequency-division multiplexing or orthogonal time frequency space respectively), according to the resulting Doppler spread and its impact on performance, is also leveraged.

3.2 RATIONALE

In cellular 5G communication, mmWave bands (30 GHz and above) are envisioned to soon complement the currently used sub-6 GHz counterparts. In this way, ever faster broadband communication can be realised due to the availability of much larger bandwidths at the higher bands compared to the lower ones. However, mmWave bands are more susceptible to blockages and absorption than the sub-6 GHz bands.

In addition, broadband 5G coverage is non-existent in many rural areas. The European Commission President Ursula von der Leyen has pointed out that still 40% of people in rural areas do not have access to fast broadband connection [39]. In addition, deploying the necessary number of terrestrial base stations to achieve 100% mmWave broadband coverage is not a viable option due to the daunting number of sites this requires [40]. Due to this, a natural question that arises is whether this gap can close through direct handheld device access from non-terrestrial platforms, such as high-altitude platform system (HAPSs) and LEO satellites being equipped with regenerative payloads to act as aerial and space base stations. This could seem much more plausible for HAPS than LEO satellites due to their lower altitude.

However, the density of HAPS, at least during the early stages of their deployments and their integration with the terrestrial network. is not expected to be adequate so to cover the demands on the ground. Instead, because LEO satellites are a more mature technology, the question is raised on whether direct broadband handheld device access can be achieved through LEO satellites. This intuitively poses great challenges due to the comparatively high altitude of these platforms and the inability of commercial devices, such as smartphones, to accommodate large antenna arrays. There are plans already for commercial deployments, such as Starlink and AST Mobile, to enable direct-to-handheld device access from their LEO constellations without any handheld device modification [41]. However, due to the lower bandwidth offered owing to the use of sub-6 GHz spectrum, and the propagation loss due to the satellite distance, there are concerns about achievable user rates being adequate to meet the ever-rising demands with the advent of 6G networks and the maximum viable satellite antenna size. Hence it is natural to ponder the possibility of utilising the bandwidth rich Ka bands (27-40 GHz) for direct-to-handheld device broadband access. An initial investigation shows that this may work under certain conditions, such as LEO satellites being almost vertically above the UE (the handheld device) and there are no adverse weather conditions [42]. If such beneficial conditions cannot be met, the only possibility for enabling broadband direct-to-handheld device access is by notably increasing the antenna gain in space so to compensate for both the higher propagation loss due to increased frequency and the higher atmospheric loss of the Ka band compared with the sub-6 GHz counterparts.

Such a design, albeit for sub-6 GHz bands, has been launched in 2022 for prototype testing by AST SpaceMobile and corresponds to a satellite with a 64 m^2 (massive) antenna [43]. However, for a ubiquitous space deployment to cover large parts of Earth such designs are not viable due to mainly the building and launching costs [44]. Due to this and leveraging the current and future trends of reducing the satellite sizes with plans for having mega-constellations of very small ones, such as cubesats, distributed beamforming from swarms of small satellites has arisen as a potential solution [44], [45]. For an adequate number of satellites in the swarm formation very high gains can be achieved under small phase synchronisation errors that can compensate for the propagation and atmospheric losses [45]. Based on these promising results, one major technical innovation of ETHER, as described earlier, is to enable direct broadband handheld device access from LEO satellites. At the bandwidth reachable at Ka band, through a novel handheld device antenna design enabling electrical beam-steering to follow the trajectory of the LEO satellites and the ability of a LEO satellite swarm to form a virtual array for distributed beamforming.

Emphasis will be given on the mitigation of time, frequency, and phase synchronisation errors that pertain the distributed beamforming formation. Of particular significance is the mitigation of the loss of phase synchronisation due to inaccuracies in the satellite position estimation.

We also note that to achieve service continuity when the service quality of a terrestrial link starts deteriorating and a handover process starts towards an NTN node or vice versa, it is assumed that the TN and NTN layers use the same spectrum pool. Hence, mitigations measures are required through dynamic spectrum management approaches that ETHER will investigate in T3.2.

3.3 KEY VALUES

The key values introduced by the realisation of use case 2 are:

- Unified hand-held device access with different RATs, either terrestrial or non-terrestrial at the bandwidth reach Ka band;
- Vertical handover mechanisms between terrestrial and non-terrestrial RATs that can cope with the high mobility of communicating non-terrestrial platforms, such as LEO satellites;
- Unified waveform design that can cope with both low-mobility and high-mobility scenarios and ML-based waveform adaptation.

3.4 KEY VALUE INDICATORS

The achieved KVIs from this use case are the followings:

- **Democracy**: By achieving seamless handheld device access by terrestrial and non-terrestrial means, ***digital inclusion*** with respect to broadband services is secured for all citizens, regardless of whether they live in urban or rural areas;
- **Environmental sustainability**: By bringing broadband services to handheld device users in remote/rural areas by non-terrestrial means instead of a 100% terrestrial deployment, around 95% of total cost of ownership (TCO) reduction is foreseen by ETHER and 3 times higher energy efficiency. This will open the door to highly ***sustainable*** 6G network ecosystems and great ***economic growth*** opportunities;
- **Personal health and protection from harm**: By offering broadband services to remote/rural areas and developing countries that lack suitable terrestrial telecommunication infrastructure, significant health benefits for citizens are expected. Wearable data from the citizens can be communicated in real time to centralised locations and so proactive actions can be taken in the case of problematic measured data from those devices. In addition, consultation services can be offered to these areas and there is also the possibility of critical operations, such as telesurgery. The latter is substantiated by the fact that studies have shown that intercontinental communication that leverages several hops through LEO satellites exhibits propagation delays that are notable smaller than 100 ms [46]. 100 ms is the maximum latency requirements for telesurgery [47].

Co-funded by the European Union

3.5 KEY VALUE ENABLERS

The key value enablers identified for use case 2 are the following:

- **Distributed beamforming from LEO satellite swarms**: Achieving very high gains through distributed beamforming among swarms of small LEO satellites that fly in close together. This is essential for direct-to-handheld device broadband communication at the bandwidth rich Ka band.
- **Handheld device antenna design**: In combination with advances in distributed beamforming from LEO satellites, of high importance for achieving the link budget required for broadband handheld device communications in the Ka band is the design of high-gain and compact user antennas that enable electronic beam-steering.
- **Unified waveform design**: Intelligent choice through AI means of the most suitable waveform that can cope with situations of notable Doppler spreads, such as the ones exerted by the communication with LEO satellites, will be brought by ETHER.
- **Vertical handovers between different RATs**: Another key value enabler introduced by ETHER is the design of energy-efficient mechanisms for the seamless handovers between different RATs, such between terrestrial and non-terrestrial RATs, that can tackle aspects such as mobility management and big differences in propagation latencies.

3.6 KEY PERFORMANCE INDICATORS

The targeted key performance indicators of use case 2 are the following:

- 100% outdoor coverage;
- 99.99999% service continuity (By service continuity we mean the seamless migration of services when switching across different radio access technologies and networks. Such a seamless migration of services can be achieved by the joint scheduling of communication and computing resources, which would make the process transparent to the users [48]. To reduce the downtime of a service during the migration process and achieve the envisioned high value of service continuity, intelligent algorithms will be leveraged that proactively decide about the joint scheduling of communication and computing resources for a particular service, as the network evolves);
- 99.99999% reliability in meeting service KPIs;
- 70% more energy-efficient vertical handover (switching from TN to NTN) compared to the SotA.

Table 3-1: Use case 2 KPIs

Identifier	Requirement	Description
ETH-KPI-UC2-01	Coverage	Provide capacity to deliver 100% coverage
ETH-KPI-UC2-02	Service continuity	99.99999%
ETH-KPI-UC2-03	Service reliability	99.99999%
ETH-KPI-UC2-04	Energy efficient handover	70% more efficient than SotA in 2023

3.7 REQUIREMENTS – FUNCTIONAL AND NON-FUNCTIONAL

The functional requirements for use case 2 are the following:

- Migration of user communication between terrestrial and non-terrestrial RATs on demand;

- The VH process can involve either the access management function (AMF) of the open air-interface core that will be used or (NG handover) or the Xn interface between the base stations that belong to the different RATs;
- Waveform selection in the communication cases, with either stationary or fast-moving platforms;
- LEO satellites work in swarm formations and transmit the same signal in a distributed way towards a user on the ground;
- Designed handheld device antenna enables electronic beam-steering, based on which the trajectory of a moving platform acting as a base station, such as a LEO satellite, can be followed.

The non-functional requirements for use case 2 are the following:

- Seamless VH process to the users;
- Broadband communication to users through either terrestrial or non-terrestrial means;
- Complete user coverage in urban and remote/rural areas.

Table 3-2: Consolidated use case 2 requirements

Identifier	Requirement	Description
ETH-REQ-UC2-FN-01	Migrate TN to NTN	Migration of the communication of a user from a terrestrial RAT to a non-terrestrial one and vice versa when is needed.
ETH-REQ-UC2-FN-02	Vertical handover	The VH process can involve either the AMF of the open air-interface core that will be used or (NG handover) or the Xn interface between the base stations that belong to the different RATs.
ETH-REQ-UC2-FN-03	Waveform	Choice of a suitable waveform in the cases of communication with either stationary or fast-moving platforms.
ETH-REQ-UC2-FN-04	LEO Swarm	LEO satellites work in swarm formations and transmit the same signal in a distributed way towards a user on the ground.
ETH-REQ-UC2-FN-05	UE beam steering	Designed handheld device antenna enables electronic beam-steering, based on which the trajectory of a moving platform acting as a base station, such as a LEO satellite, can be followed.
ETH-REQ-UC2-NF-01	Vertical handover	Seamless VH process to the users.
ETH-REQ-UC2-NF-02	Broadband	Broadband communication to then users by either terrestrial or non-terrestrial means.
ETH-REQ-UC2-NF-03	Coverage	Complete user coverage in urban and remote/rural areas.

4 USE CASE 3: AIR-SPACE SAFETY CRITICAL OPERATIONS

4.1 DESCRIPTION

Aircraft require different communications technologies along their travel journeys from one airport to another, as shown in Figure 4-1. In this use case, the vision of ETHER hybrid multi-layered network will be demonstrated, comprising of terrestrial, HAPS, and space-based components in serving aircraft departing from one airport and landing in another airport, possibly passing through the oceanic airspace. The operational requirements for the various technical options of aircraft communication systems in the various phases of flight are assessed against a set of values for some parameters. These are denoted by the term "required communication performance (RCP) type", which is quantified in terms of communication transmission delay, data rate, continuity, availability, integrity. These will be primarily used to evaluate the RCP in the provision of air traffic services.

This intended use case aims to provide a seamless high-resilient aeronautical data network for safety-critical services to support the following objectives:

- Meet the RCP of the different aircraft flight phases;
- Provide guaranteed E2E aircraft communication services subject to optimal network performance and efficient resource allocation;
- Provision resources and/or migrate service data in network edges that supports advanced avionics services.

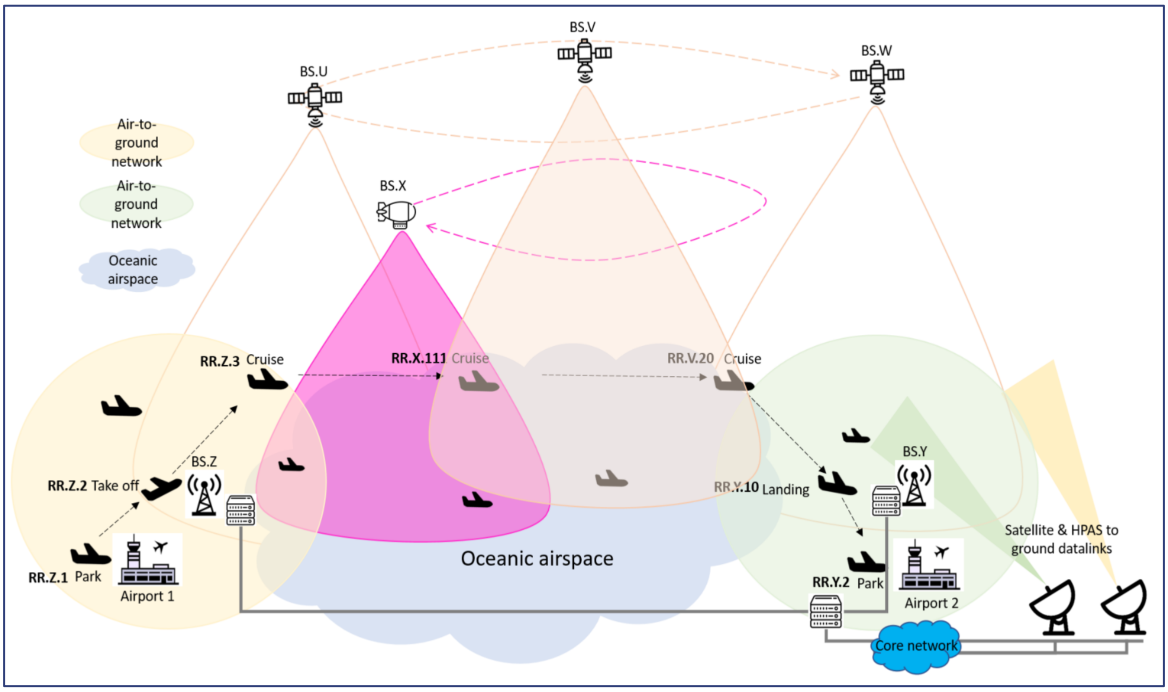

Figure 4-1: Airspace safety critical operations

4.2 RATIONALE

Existing aeronautical data networks experience capacity shortage and bandwidth constraints as more aircraft enter in operations. Emerging avionic air traffic management (ATM) systems, and next generation communication, navigation, and surveillance (CNS) features, as well as aeronautical service providers demand reliable data connectivity with high QoS provisioning.
Therefore, specific areas should be identified for which the existing aeronautical communication networks and ATM systems require major adaptations from the terrestrial, HAPS, or satellite to meet the RCPs of the flight phases of aircraft. These consequently lead to the ETHER hybrid multi-layered network, which should be designed to leverage the fast-growing space-based systems, primarily LEO satellites and HAPS, and terrestrial 5G/6G networks integration solutions. The results shall be driven towards developing agile multi-layer communication architecture that can support the existing and emerging avionic services and applications, particularly the RP required for aircraft communications.

4.3 KEY VALUES

New technologies introduced in the ETHER project will provide the following values:

- Improved air-to-ground datalink bandwidth;
- Flexible and reconfigurable network resource management;
- Support guaranteed and differentiated E2E QoS;
- Optimize network resource allocation and performance.

4.4 KEY VALUE INDICATORS

The following key value indicators show the value creation for the delivered aircraft communication services and single pilot operations by supporting the following:

- Novel avionic services and aircraft communication operations;
- Aeronautical networks capacity and links orchestration;
- Efficient aeronautical service provisioning optimisation;
- Aeronautical services provisioning cost reduction;
- Single pilot availability and safe flight.

4.5 KEY VALUE ENABLERS

The following enablers provide some of the main keys to support the use case, considering the network topology components, and mechanism to run the scenarios:

- ETHER 5G network and satellite simulation or emulation technologies;
- 3D network communication links orchestration;
- Agile network design and configurations tailored for efficient avionics communication services provisioning;
- SDN-based traffic flows steering and users to cell association.

4.6 KEY PERFORMANCE INDICATORS

Aircraft are offered different services during their flight phases, which also differ according to the type of aircraft, whether crewed or single pilot. Standard data communication, standard surveillance communication, and strict data communication services require different communication performance, which is measured against the following metrics [49]:

- 100% network coverage;
- 99.99999% service continuity;
- 99.99999% service reliability;
- 95 percentile delay of 250 ms;
- 99.9 percentile delay of 500 ms;
- Performance integrity 10^{-4} to 10^{-6};
- 100% service data migration;
- > 80% more energy efficient resource allocation than SotA.

Table 4-1: Use case 3 KPIs

Identifier	**KPI**	**Description**
ETH-KPI-UC3-01	Network coverage	100% network coverage
ETH-KPI-UC3-02	Service continuity	99.99999% service continuity
ETH-KPI-UC3-03	Service reliability	99.99999% service reliability
ETH-KPI-UC3-04	Delay	95 percentile delay of 250 ms 99.9 percentile delay of 500 ms
ETH-KPI-UC3-05	Performance integrity	Performance integrity 10^{-4} to 10^{-6}
ETH-KPI-UC3-06	Resource allocation	> 80% more energy efficient resource allocation than SotA
ETH-KPI-UC3-07	Service data migration	100% service data migration

4.7 REQUIREMENTS – FUNCTIONAL AND NON-FUNCTIONAL

4.7.1 Functional requirements

This subsection provides a summary of the main ETHER functional requirements for UC 3 that have been considered below to drive this proposed use case architecture performance evaluation studies that will be reported in this deliverable report. The following functional requirements have been identified for this use case:

- **RAN in TN, HAPS, and SAT** – enables the 3D network layers to communicate with the aircraft user equipment, with a possibility to link them through a unified RAN framework.
- **Open 5GCN** – is required to communicate with the core network user mobility and traffic management gateway functions through specific APIs;
- **Channel emulation** – required for satellite channel, aircraft UE channel, and all the channels of deployed base stations in the 3 layers including terrestrial, HAPS, and satellite ones;
- **Network resource monitoring** – contributes towards E2E service communications and management with guaranteed QoS, adaptive scheduling for computation offloading and contents caching;
- **Multilink functionality** – in flight operations are justified by the RCPs and connectivity resilience related to the impact of safety and the efficiency of ATM operations;
- **Network orchestrator** – self-evolving 3D network links and edge resources orchestration, employing predictive data analytics associated with traffic monitoring, traffic prioritisation, resource allocation per flight phase and meeting the expected E2E network performance;

- **3D unified SDN management** – manages the relationship between the different controllers running in the 3D network layers. The emphasis vision for the centralised controllers is focused on improving the control plane efficiency by minimising the signalling required prior to aircraft communication transmission and improving the data plane in the different integrated layers;
- **Service performance determinism** – ensures E2E performance guarantee perspective, from end-device to the last application function, which require evolving time sensitive network (TSN) capabilities and integrating model predictive control (MPC) solutions for dynamic ATM applications.

4.7.2 Non-functional requirements

The following non-functional requirements specify the quality attributes of the ETHER use case architecture system. They essentially specify how the use case system architecture should behave under its constraints in meeting the RCPs QoS attributes and the limitations of the architecture functionalities. The following functional requirements have been identified for this use case:

1. **RCPs requirements** – where the capacity provided by the ETHER network architecture should be efficiently allocated to support scenarios requesting reliable, resilient, low latency and high data rates connectivity with integrity, considering high aircraft traffic density. The scenarios are intended to meet the RCPs requirements of the different ATM communication services delivered in the different flight phases;
2. **3D RAN low latency** – where the overall service latency depends on the delay at the different 5G RAN radio interfaces deployed in the different 3D network layers, the transmission within the 5G RANs deployed in terrestrial, HAPS and satellites, the transmission to a server which may be external to the whole 5G network, and the data processing. Some of these elements depend directly on the 5G RAN itself, whereas for others the impact can be reduced by suitable interconnections between the 5G RAN and external services by allowing, for example, local services hosting on network edges;
3. **Handover reliability and delay** – considers delay resulting in the HH process during the process of transferring data from one cell to another, inside the same access core network (i.e., intra-system handover). Or, VH which involves handover between different access technologies when they are available, but the objective remains the same: transparently guarantee the session continuity from a final aircraft users' point of view;
4. **3D network programmability** – turns the 3D network layers from connectivity platform to service enablement platforms by applying service-based architecture patterns (RESTful-based HTTP APIs) across all layers;
5. **3D network connected intelligence** – contributes to building up a data and connectivity infrastructure supporting cooperation of trusted AI functions from different network layers;
6. **3D network performance optimisation** – contributes to optimised network resources (computation, communication, and storage) provisioning that leverages AI-enabled data analytics and ensures E2E QoS requirements that support highly critical avionics services in an optimal and flexible manner.

4.7.3 Consolidated requirements for use case 3

The requirements above were reviewed by the project team, this results in the following consolidated requirements list for use case 3.

Table 4-2: Consolidated use case 3 requirements

Identifier	Requirement	Description
ETH-REQ-UC3-FN-01	RAN in TN, HAPS, and SAT	Enables the 3D network layers to communicate with the aircraft user equipment, with a possibility to link them through a unified RAN framework.
ETH-REQ-UC3-FN-02	Open 5GCN	Required to communicate with the core network resource allocation and user mobility and management gateway functions through specific exposed APIs.
ETH-REQ-UC3-FN-03	Channel emulation	Required for satellite channel, aircraft UE channel, and all the channels of deployed base stations in the 3 layers including terrestrial, HAPS, and satellite ones.
ETH-REQ-UC3-FN-04	Network resource monitoring	Contributes towards E2E service communications and management with guaranteed QoS, adaptive scheduling for computation offloading and contents caching; in this context resources means information on links, ports, power and spectrum.
ETH-REQ-UC3-FN-05	Multilink functionality	In-flight operations are justified by RCP and connectivity resilience related to the impact of safety and the efficiency of ATM operations; standards based and or open-source solutions preferred.
ETH-REQ-UC3-FN-06	Network orchestrator	3D network links and edge resources orchestration, employing predictive data analytics associated with traffic monitoring, traffic prioritisation, resource allocation per flight phase and meeting the expected E2E network performance.
ETH-REQ-UC3-FN-07	3D unified SDN management	Manages the relationship between the different controllers running in the 3D network layers. The emphasis vision for the centralised controllers is focused on improving the SDN control plane efficiency by minimising the signalling required prior to aircraft communication transmission and improving the data plane in the different integrated layers.
ETH-REQ-UC3-FN-08	Service performance determinism	Ensures E2E performance guarantee perspective, from end-device to the last application function, which require evolving TSN capabilities and integrating MPC solutions for dynamic ATM applications.
ETH-REQ-UC3-NF-01	RCP requirements	Where the capacity provided by the ETHER network architecture should be efficiently allocated to support scenarios requesting reliable, resilient, low latency and high data rates connectivity with integrity, considering high aircraft traffic density. The scenarios are intended to meet the RCPs requirements of the different ATM communication services delivered in the different flight phases.

Identifier	Requirement	Description
ETH-REQ-UC3-NF-02	3D RAN low latency	Where the overall service latency depends on the delay at the different 5G RAN radio interfaces deployed in the different 3D network layers, the transmission within the 5G RANs deployed in terrestrial, HAPSs, and satellites, the transmission to a server which may be external to the whole 5G network, and the data processing. Some of these elements depend directly on the 5G RAN itself, whereas for others the impact can be reduced by suitable interconnections between the 5G RAN and external services by allowing, for example, local services hosting on network edges.
ETH-REQ-UC3-NF-03	Handover reliability and delay	Considers delay resulting in the HHHH process during the process of transferring data from one cell to another, inside the same access core network (i.e., intra-system handover). Or, VH, which involves handover between different access technologies when they are available, but the objective remains the same: transparently guarantee the session continuity from a final aircraft users' point of view.
ETH-REQ-UC3-NF-04	3D network programmability	Turns the 3D network layers from connectivity platform to service enablement platforms by applying service-based architecture patterns (RESTful-based HTTP APIs) across all layers.
ETH-REQ-UC3-NF-05	3D network connected intelligence	Contributes to building up a data and connectivity infrastructure supporting cooperation of trusted AI functions from different network layers.
ETH-REQ-UC3-NF-06	3D network resources optimisation	Contributes to optimised network resource provisioning that leverages AI-enabled data analytics and ensures E2E QoS requirements that support highly critical avionics services in an optimal and flexible manner.

5 CONSOLIDATING THE KPIS AND REQUIREMENTS

5.1 KEY VALUES AND KEY VALUE INDICATORS

The key values for use case 1 tend to be clustered around service efficiency and scalability whilst delivering the required service parameters. The key value indicators therefore reflect this and represent differing aspects that can be measured. Use case 2 considers three key values focussed on the unification of NTN into 6G resulting in three KVIs; democratisation, economic growth, and innovation. The key values for use case 3 look at improved connectivity, support for E2E service and resource management in support of optimised service delivery to aircraft and the key values indicators reflect this. There are significant similarities between the use case 1 and use case 3 key values.

The reviews of published documents summarised in appendix A find that there are a few papers that have considered key values and KVIs:

- 6GIA in their paper [7] lists twelve key values indicators "*Environmental sustainability, societal sustainability, economical sustainability and innovation, democracy, cultural connection, knowledge, privacy and confidentiality, simplified life, digital inclusion, personal freedom, personal health and protection from harm, trust*";
- GSOA in their whitepaper [17] define four key values "*ubiquity, continuity, scalability, and resilience*";
- NGMN Alliance defines in their paper [29] the following eight KVIs "*digital inclusion, energy efficiency, environmental impact, native trustworthiness, support for regulated and unregulated services, automation of E2E service delivery, automated network programmability, AI as a Service*".

Reviewing these and noting also that these third-party key values/KVIs cover many use cases beyond the scope of ETHER, no identified additional key values and KVIs need to be added.

5.2 KEY PERFORMANCE INDICATORS

5.2.1 From the published document review

In [5] the 5G PPP defines KPIs for beyond 5G and how they should be defined. The actual target values stated therein are maxima across all use cases and not necessarily representative. The KPIs they define are:

- Peak data rate;
- User experienced data rate;
- Area traffic capacity;
- Bandwidth;
- Connection density;
- Latency;
    - User plane latency,
    - Control plane latency;
- Reliability;
- Peak spectral efficiency;
    - 5th percentile user spectral efficiency,
    - Average spectral efficiency;
- Energy efficiency;
- Energy efficiency in NFV;

- Higher-accuracy positioning;
- QoE.

An additional non-functional requirement for this project is therefore that ETHER should follow the definitions of the KPIs in [5]. This is carried forward to be included in section 5.3 below.

The KPIs defined in are similar [8] are essentially the same ambitious parameters as the 5G PPP; whereas in [27] the NextG Alliance also has the same KPIs in less detail but do mention security as a potential KPI. One6G in their use case analysis [34] do link different KPIs to different use cases as has been the case in ETHER, no additional KPIs have been identified by One6G.

5.2.2 ETHER KPI list

The KPIs from all three use cases are shown below in Table 5-1.

Table 5-1: Amalgamated KPI list

Identifier	KPI	Description
ETH-KPI-UC1-01	Energy Efficiency	>75% compared to SotA
ETH-KPI-UC1-02	Latency	<5 ms (excluding propagation delay)
ETH-KPI-UC1-03	Network coverage	100% network coverage
ETH-KPI-UC1-04	Service continuity	99.99999% service continuity
ETH-KPI-UC1-05	Service reliability	99.99999% service reliability
ETH-KPI-UC2-01	Coverage	Provide capacity to deliver 100% coverage
ETH-KPI-UC2-02	Service continuity	99.99999%
ETH-KPI-UC2-03	Service reliability	99.99999%
ETH-KPI-UC2-04	Energy efficient handover	70% more efficient than state of the art in 2023
ETH-KPI-UC3-01	Network coverage	100% network coverage
ETH-KPI-UC3-02	Service continuity	99.99999% service continuity
ETH-KPI-UC3-03	Service reliability	99.99999% service reliability
ETH-KPI-UC3-04	Delay	95 percentile delay of 250 ms 99.9 percentile delay of 500 ms
ETH-KPI-UC3-05	Performance integrity	Performance integrity 10^{-4} to 10^{-6}
ETH-KPI-UC3-06	Resource allocation	> 80% more energy efficient resource allocation than SotA
ETH-KPI-UC3-07	Service migration	100% service data migration

5.3 REQUIREMENTS

5.3.1 From the published document review

In [3], some of the high-level requirements identified by 5G PPP are not relevant to the ETHER use cases, however those relating to reliability, coverage, and energy efficiency are but are already captured. No additional requirements are needed from this for the ETHER project.

In [21], specifically ITU-T Y.3200, the ITU-T makes some recommendations for NTN and hybrid TN/NTN. Two of its general recommendations are directly applicable for ETHER:

- It is required for fixed, mobile and satellite converged network to support service continuity during handover between different access networks;
- It is required for fixed, mobile and satellite converged networks to support best-effort QoS for supported services and applications.

A third requirement can be identified:

- Where they become applicable to the ETHER use cases, the project shall meet the requirements identified in ITU-T Y.3200.

In [28] where the Next G Alliance's use cases align with ETHER so do their requirements. In their roadmap [27] they do define some environmental requirements that go beyond the energy saving requirements defined in ETHER. These additional Next G Alliance requirements are more relevant for higher technology readiness level (TRL) projects than ETHER.

The NGMN Alliance has not yet published any detailed requirements however in their 2023 position statement [32] they do make the request that 6G should be, as far as possible, be evolutionary minimising the hardware implications for any future upgrades. This is more relevant for higher TRL projects than ETHER, nevertheless this might be well to be remembered when making design decisions.

Table 5-2: Additional general requirements

Identifier	Requirement	Description
ETH-REQ-GEN-FN-01	Service continuity	Fixed, mobile and satellite converged network shall support service continuity during handover between different access networks.
ETH-REQ-GEN-FN-02	Minimum service	Fixed, mobile and satellite converged networks shall support best-effort QoS for supported services and applications.
ETH-REQ-GEN-NF-01	ITU	Where they become applicable to the ETHER use cases, the project shall meet the requirements identified in ITU-T Y.3200 [21].
ETH-REQ-GEN-NF-02	5G PPP	ETHER should follow the 5G PPP definitions of the KPIs [4].

5.3.2 ETHER functional requirements

All the functional requirements for the use cases in ETHER are provided below in Table 5-3.

Table 5-3: Consolidated functional requirements

Identifier	Requirement	Description
ETH-REQ-UC1-FP-01	Payload FPGA resources management	Manage and deploy in a dynamic and autonomous way FPGA resources considering specific context.
ETH-REQ-UC1-FP-02	Payload FPGA resources availability	Control available resources and its percentage of use.
ETH-REQ-UC1-FP-03	Payload FPGA services deployment	Ensure that services are deployed correctly using virtualisation techniques plus containers.
ETH-REQ-UC1-FP-04	Payload FPGA resources sharing	Ensure proper multiplexing for resource sharing, considering interfaces (UART, ethernet) and other hardware resources (memory, buffers, analogue-to-digital converters).
ETH-REQ-UC1-DT-01	Intermittent – scheduled contacts	Agreement to establish a contact at a particular time.
ETH-REQ-UC1-DT-02	Intermittent – opportunistic contacts	Contacts are not scheduled but present themselves unexpectedly.
ETH-REQ-UC1-DT-03	Intermittent – predicted contacts	Predicted contacts have no fixed schedule, but instead are predictions of likely contact times and durations based on a history of previous observed contacts or some other information (satellite ephemerides) and ML in ETHER.

Identifier	Requirement	Description
ETH-REQ-UC1-DT-04	Congestion and flow control	Device messages arrive at destination, vertical and horizontal Handover, support of congestion and flow control, message retransmissions.
ETH-REQ-UC1-DT-06	Connection discontinuity	Support of a low-density LEO constellation with service link and feeder link discontinuity.
ETH-REQ-UC1-DT-07	Store and forward	Support for S&F on low-density LEO constellation, to solve connection discontinuity, and support of S&F over vertical and HHs according to ML in ETHER.
ETH-REQ-UC1-DT-09	Mobility management	Dynamic organisation of tracking areas, or broadcasting of ephemerides to end devices to assist them in using network and power resources efficiently.
ETH-REQ-UC1-SE-01	Sample processing	Need to influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-02	Joint sample and transmit	Need to influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-03	Support for E2E information handling beyond the sample and transmit	Need to influence the whole information chain from the point we generate the information, encoding, transmitting, and receiving. Furthermore, the utilisation of information to achieve a certain goal, for example datasets (or partial datasets) to train an ML algorithm.
ETH-REQ-UC1-SE-04	Content caching	Need to find the criteria for reusable traffic to effectively cache the freshest and also valuable information proactively.
ETH-REQ-UC2-FN-01	Migrate TN to NTN	Migration of the communication of a user from a terrestrial RAT to a non-terrestrial one and vice versa when is needed.
ETH-REQ-UC2-FN-02	Vertical handover	The VH process can involve either the AMF of the open air-interface core that will be used or (NG handover) or the Xn interface between the base stations that belong to the different RATs.
ETH-REQ-UC2-FN-03	Waveform	Choice of a suitable waveform in the cases of communication with either stationary or fast-moving platforms.
ETH-REQ-UC2-FN-04	LEO swarm	LEO satellites work in swarm formations and transmit the same signal in a distributed way towards a user on the ground.
ETH-REQ-UC2-FN-05	UE beam steering	Designed handheld device antenna enables electronic beam-steering, based on which the trajectory of a moving platform acting as a base station, such as a LEO satellite, can be followed.
ETH-REQ-UC3-FN-01	RAN in TN, HAPS, and SAT	Enables the 3D network layers to communicate with the aircraft user equipment, with a possibility to link them through a unified RAN framework.
ETH-REQ-UC3-FN-02	Open 5GCN	Required to communicate with the core network resource allocation and user mobility and management gateway functions through specific exposed APIs.
ETH-REQ-UC3-FN-03	Channel emulation	Required for satellite channel, aircraft UE channel, and all the channels of deployed base stations in the 3 layers including terrestrial, HAPS, and satellite ones.

Identifier	Requirement	Description
ETH-REQ-UC3-FN-04	Network resource monitoring	Contributes towards E2E service communications and management with guaranteed QoS, adaptive scheduling for computation offloading and contents caching; in this context resources means information on links, ports, power and spectrum.
ETH-REQ-UC3-FN-05	Multilink functionality	In-flight operations are justified by RCP and connectivity resilience related to the impact of safety and the efficiency of ATM operations; standards based and or open-source solutions preferred.
ETH-REQ-UC3-FN-06	Network orchestrator	3D network links and edge resources orchestration, employing predictive data analytics associated with traffic monitoring, traffic prioritisation, resource allocation per flight phase and meeting the expected E2E network performance.
ETH-REQ-UC3-FN-07	3D unified SDN management	Manages the relationship between the different controllers running in the 3D network layers. The emphasis vision for the centralised controllers is focused on improving the SDN control plane efficiency by minimising the signalling required prior to aircraft communication transmission and improving the data plane in the different integrated layers.
ETH-REQ-UC3-FN-08	Service performance determinism	Ensures E2E performance guarantee perspective, from end-device to the last application function, which require evolving TSN capabilities and integrating MPC solutions for dynamic ATM applications.
ETH-REQ-GEN-FN-01	Service continuity	Fixed, mobile and satellite converged network shall support service continuity during handover between different access networks.
ETH-REQ-GEN-FN-02	Minimum service	Fixed, mobile and satellite converged networks shall support best-effort QoS for supported services and applications.

5.3.3 ETHER non-functional requirements

All the non-functional requirements for the three use cases in ETHER are provided below in Table 5-4.

Table 5-4: Consolidated ETHER non-functional requirements

Identifier	Requirement	Description
ETH-REQ-UC1-FP-05	Payload System performance metrics	Extract metrics of the system when enabled to monitor different parameters of the system: power consumption, CPU, disk and memory usage.
ETH-REQ-UC1-DT-05	High latency, low data rate	Support for high latency at low data rates for delay-tolerant IoT applications.
ETH-REQ-UC1-DT-08	Traffic model MAR	MAR exception reports (notify sporadic events).
		MAR periodic reporting (regular transmission).
		Firmware updates.
ETH-REQ-UC1-DT-09	Mobility Management	Dynamic organisation of tracking areas, or broadcasting of ephemerides to end devices to assist them in using network and power resources efficiently.
ETH-REQ-UC1-DT-10	Support for different services	Support of multi-radio applications based in NB-IoT using ML in ETHER and orchestrated by the MANO.
ETH-REQ-UC2-NF-01	Vertical handover	Seamless VH process to the users.
ETH-REQ-UC2-NF-02	Broadband	Broadband communication to then users by either terrestrial or non-terrestrial means.
ETH-REQ-UC2-NF-03	Coverage	Complete user coverage in urban and remote/rural areas.

Identifier	Requirement	Description
ETH-REQ-UC3-NF-01	RCP requirements	Where the capacity provided by the ETHER network architecture should be efficiently allocated to support scenarios requesting reliable, resilient, low latency and high data rates connectivity with integrity, considering high aircraft traffic density. The scenarios are intended to meet the RCP requirements of the different ATM communication services delivered in the different flight phases.
ETH-REQ-UC3-NF-02	3D RAN low latency	Where the overall service latency depends on the delay at the different 5G RAN radio interfaces deployed in the different 3D network layers, the transmission within the 5G RANs deployed in terrestrial, HAPSs, and satellites, the transmission to a server which may be external to the whole 5G network, and the data processing. Some of these elements depend directly on the 5G RAN itself, whereas for others the impact can be reduced by suitable interconnections between the 5G RAN and external services by allowing, for example, local services hosting on network edges.
ETH-REQ-UC3-NF-03	Handover reliability and delay	Considers delay resulting in the HHHH process during the process of transferring data from one cell to another, inside the same access core network (i.e., intra-system handover). Or, VH, which involves handover between different access technologies when they are available, but the objective remains the same: transparently guarantee the session continuity from a final aircraft users' point of view.
ETH-REQ-UC3-NF-04	3D network programmability	Turns the 3D network layers from connectivity platform to service enablement platforms by applying service-based architecture patterns (RESTful-based HTTP APIs) across all layers.
ETH-REQ-UC3-NF-05	3D network connected intelligence	Contributes to building up a data and connectivity infrastructure supporting cooperation of trusted AI functions from different network layers.
ETH-REQ-UC3-NF-06	3D network resources optimisation	Contributes to optimised network resource provisioning that leverages AI-enabled data analytics and ensures E2E QoS requirements that support highly critical avionics services in an optimal and flexible manner.
ETH-REQ-GEN-NF-01	ITU	Where they become applicable to the ETHER use cases, the project shall meet the requirements identified in ITU-T Y.3200 [21].
ETH-REQ-GEN-NF-02	5G PPP	ETHER should follow the 5G PPP definitions of the KPIs [4].

6 SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The three ETHER use cases have been described and their resulting KVIs, KPIs and requirements have been identified. This has been supplemented by a review of published material looking at the possibilities for 6G from major organisations around the world.

From this analysis fifteen KPIs, thirty functional requirements and eighteen non-functional requirements have been identified. These will together provide direction for the work in the ETHER project.

6.2 CONCLUSIONS

The ETHER project follows the three-stage ITU-T approach [50], commonly adopted by the telecommunications industry, namely such influential standards developing organisations SDOs like 3GPP or ETSI. The importance of Stage 1 is fundamental to the success of subsequent stages and the overall process. The task of Stage 1 is to define the overall service description from the user's point of view (e.g., expressed in the definition of use cases), and then translate it into a set of requirements, among which an important area are the quantitative requirements described by KPIs. Only on this basis is it possible to move to Stage 2 in which the functional model of the implementation driving the architecture, the information flow model, and the behaviour of functional entities are defined. Only on this basis is it possible to move to Stage 2 in which the functional model of the service implementation driving the solution architecture, the information flow model, and the behaviour of functional entities are defined. Then the placement of these latter is possible as well as proceeding with Stage 3 in which data exchange protocols and formats are specified.

This document serves as an outcome of Stage 1, triggering the ETHER project activities of the subsequent stages. Its early draft fed into the design work reported in D2.1 (initial architecture) and will influence the further design work to be reported in D2.4 (final architecture, to be accompanied also with its techno-economical evaluation in D2.3). This combined requirements and design will be used for design of specific ETHER mechanisms, functional entities, and solutions: in WP3 "Key technological enablers for the seamless and energy-efficient ETHER network operation", to be reported on in D3.1 and D3.2; and the work in WP4 "Zero-touch data-driven network and service orchestration in the 3D ETHER architecture", to be reported in D4.1 and D4.2. WP2 in cooperation with P3 and WP4 will provide also Stage 3 interface control documents (ICDs) for interfaces newly specified by the ETHER project or requested extensions of existing standardised interfaces resulting from the Stage 2 concepts driven by the Stage 1 requirements coming from this document.

Finally, the KPIs will form part of the evaluation work in WP5 "Technology Integration and Live Demonstration of ETHER technologies" that will implement the ETHER system designed in WP2-WP4, and will be reported on in D5.1, D5.2, and D5.3.

It should also be noted that although the ETHER system is to be demonstrated on three above-presented use cases, the project does not intend to provide a closed, narrow solution limited to the specifics of these use cases. The ETHER project's attitude to designing a capacious system open to a wide variety of applications is guided by a thorough review and analysis of various visions and approaches, which is presented in Annex A included at the end of this document.

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APPENDIX A – REVIEW OF PUBLISHED DOCUMENTS

A.1 SCOPE

This appendix summarises the review of each document identified in Table 1-1.

The reason for considering each organisation's documents is presented then each document is examined for:

- Use cases;
- KVIs;
- KPIs;
- Requirements;
- Architectural guidelines; and
- Mention of NTN.

We want to be clear at the outset that the authors of this deliverable recognise the very many hours of work by many talented people around the world have gone in to each and every one of these documents – this review focusses on relevance to ETHER and in particular in identifying relevant information for this deliverable.

In the following sections the publicly available content is summarised in tables against the bullet points above and key finding(s) for ETHER identified. These sections are sorted in alphabetical order by organisation.

A.2 5G AMERICAS

They state on their website that "*5G Americas is an industry trade organisation composed of leading telecommunications service providers and manufacturers. The organisation's mission is to advocate for and foster the advancement and full capabilities of LTE wireless technologies and their evolution to 5G, throughout the ecosystem's networks, services, applications and connected devices in the Americas*".

They do not have a white paper on 6G but do describe their view of the roadmap to 5G Advanced.

Table A-0-1: 5G America roadmap review

5G Americas	Becoming 5GAdvanced the 3GPP 2025 roadmap [2]
Use cases	Nine use case families are mentioned, these are targeted on the developments expected for 5G advanced but may form useful precursors ETHER
KVIs	Nothing explicitly defined
KPIs	A variety of device/service KPIs are provided that may have some relevance

5G Americas	Becoming 5GAdvanced the 3GPP 2025 roadmap [2]
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Both NTN and NTN-IoT are described

Key finding: The paper provides some useful 5G Advanced details that may provide a baseline for ETHER.

Key finding: The paper provides some data on energy efficiency that may be leveraged in ETHER.

A.3 5G PPP/6GIA

The 5G Infrastructure Public-Private Partnership (5G PPP) is represented by the European Commission (EC) and 6G Industry Association. This is the main driver of European 5G/6G developments and as such as somewhat related to the funding for the ETHER project.

Table A-0-2: 5G PPP European 6G vision review

5G PPP	European vision for the 6G network ecosystem [3]
Use cases	Nothing explicitly defined
KVIs	Nothing explicitly defined
KPIs	Numerical values akin to those provided for 5G are proposed – see below
Requirements	Some high-level requirements are identified – see below
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Section 4.6 refers to NTN/satellite roles, in essence summarising the Strategic Research and Innovation Agenda (SRIA) recommended research directions

The document does suggest some KPIs – for example in its Figure 3-3 reproduced below. The focus on large numerical value increases is ambitious but not totally consistent with those preferring a more evolutionary approach for 6G compared to 5G.

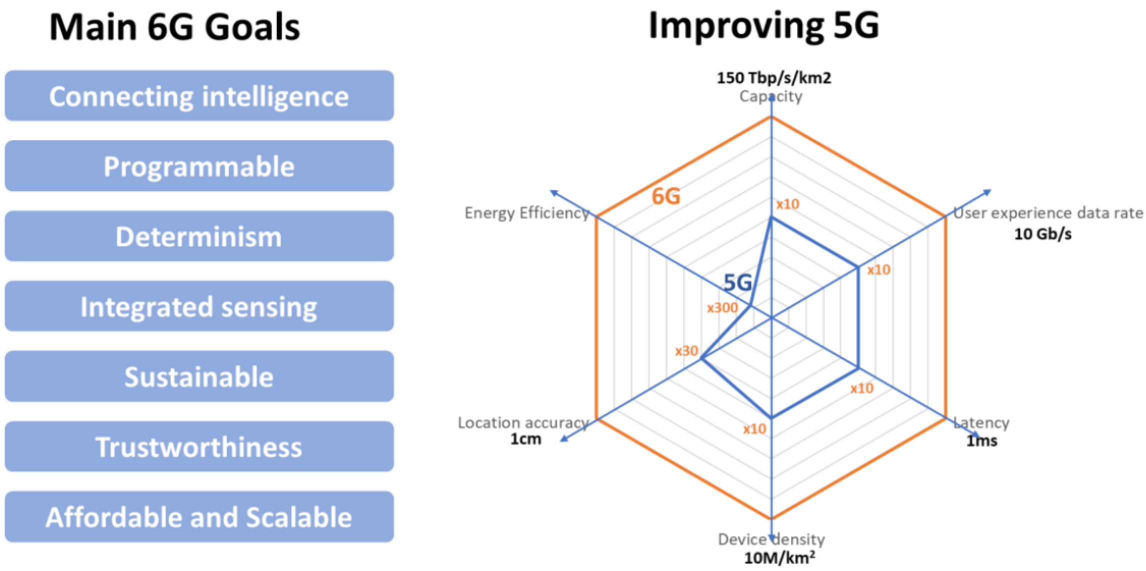

Figure A-0-1: 5G PPP goals for 6G

Its Figure 4-1 (shown below) links the requirements they have identified with the KPIs and how AI/ML can assist in this.

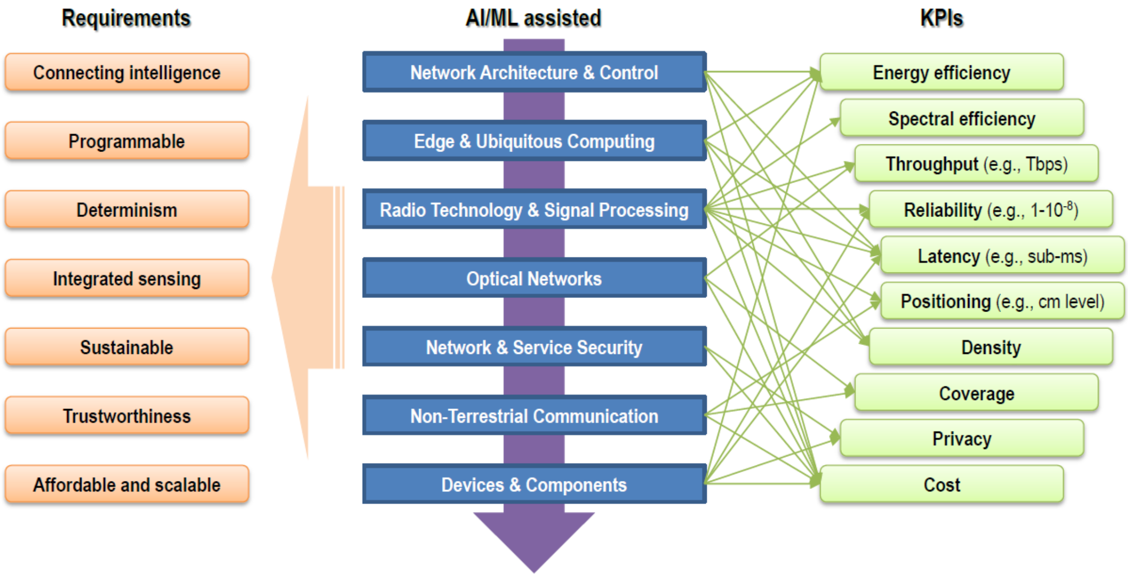

Figure A-0-2: 5G PPP linking requirements to KPIs using AI/ML assistance

Key finding: The links showing how AI/ML can assist the creation of KPIs and related implementation where ETHER shares them with this white paper.

Key finding: The performance KPIs may be applicable to ETHER.

Table A-0-3: 5G PPP 6G architecture landscape review

5G PPP	**The 6G architecture landscape V6.0 [4]**
Use cases	Refers to Hexa-X use cases that are reviewed below
KVIs	Nothing explicitly defined
KPIs	Identifies three sustainability KPIs: • KPI1 (Societal target): Enable the reduction of emissions of >30% CO_2 eq. in 6G-powered sectors of society • KPI2 (Economic target): Reduce TCO of 6G by >30% • KPI3 (Environmental target): reduce energy transmitted per bit by >90%
Requirements	Nothing explicitly defined
Architectural guidelines	Significant thought on architecture (naturally), in particular identifying eight architectural enablers: • Intelligent network • Sustainable network • Secure network • Versatile radio access network • Localisation and sensing • Programmable networks • Management and orchestration
Satellite/NTN	Explicitly mentioned in the context of flexible networks

The paper explicitly states in its conclusions "*The outcome of this white paper is building a common consolidated picture of the 5G PPP projects view on the future 6G Architecture and research directions, which aims to set the architectural foundation for the upcoming European program, namely smart networks and services (SNS) joint undertaking (JU)*".

Key finding: It is clear than when considering the architecture for ETHER that there is the definite and implied requirement to follow the precepts laid down in this document as far as is found to be possible.

Table A-0-4: 5G PPP Beyond 5G KPIs review

5G PPP	**Whitepaper - Beyond 5G/6G KPIs and target values [5]**
Use cases	Nothing explicitly defined
KVIs	Nothing explicitly defined

5G PPP	Whitepaper - Beyond 5G/6G KPIs and target values [5]
KPIs	Proposes KPIs and values to be measured, an overview is provided below.
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Not mentioned

Overview of KPIs listed:

- Latency (control and user plane considered separately);
- Capacity (multiple KPIs);
- Packet loss and reliability;
- Energy efficiency;
- Channel performance
- Electric and magnetic fields (EMF) exposure;
- Localisation accuracy;
- Service availability and reliability.

Key finding: The paper defines KPIs and provides values that should be used where appropriate (as, for example, not all the KPIs will apply) in ETHER unless there is a valid reason for changing.

Table A-0-5: 5G PPP KPI measurement review

5G PPP	KPIs measurement tools [6]
Use cases	Nothing explicitly defined
KVIs	Nothing explicitly defined
KPIs	Proposes methods to measure and report KPIs
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Not mentioned

Key finding: The methodology used to measure and report KPIs should be reviewed and adopted in this project.

Co-funded by the European Union

Table A-0-6: 6GIA Societal values review

6GIA	What societal values will 6G address? [7]
Use cases	The paper defines six use case areas – see below
KVIs	The paper defines eleven key values that are linked to the UN SDGs – see below – and defines a process for deriving KVIs and quantified KPIs
KPIs	See KVIs above
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Satellite mentioned in two use case areas (their 1 and 2) and NTN in two KV enablers on sustainability

Use case areas:

1 – Emergency response & warning systems;
2 – Smart city with urban mobility;
3 – Personal health monitoring & actuation everywhere;
4 – Living and working anywhere;
5 – Assistance from twinned cobots;
6 – Sustainable food production.

The key values are:

1. Environmental sustainability;
2. Societal sustainability;
3. Economical sustainability and innovation;
4. Democracy;
5. Cultural connection;
6. Knowledge;
7. Privacy and confidentiality;
8. Simplified life;
9. Digital inclusion;
10. Personal freedom;
11. Personal health and protection from harm;
12. Trust.

Key finding: The methodology used to flow down to KPIs should be reviewed and adopted in this deliverable; likewise, their key values can be reviewed and adopted as appropriate.

Key finding: The use case areas are different from the ETHER use cases however there are some similarities and synergies, for example between their emergency response & warning systems and ETHER air-space safety critical operations and these can be leveraged in D2.2.

A.4 6G FLAGSHIP

This is a research program headed by the University of Oulu that had produced several white papers on 6G in coordination with multiple other organisations.

Table A-0-7: 6G flagship broadband connectivity review

6G Flagship	White paper on broadband connectivity in 6G [8]
Use cases	Nine use cases are defined (see below)
KVIs	Nothing explicitly defined
KPIs	See table below, they note that "*It is unlikely that all of these requirements will be simultaneously supported, but different use cases will have different sets of KPIs, and only some will have the maximum requirements mentioned above*"
Requirements	Nothing explicitly defined
Architectural guidelines	Section 3 has some architecture discussion as part of the review of the infrastructure enablers[1]
Satellite/NTN	Has a section on "*Integrated Space and Terrestrial Networks*"

Use cases:

1. Extreme capacity xhaul;
2. Enhanced hotspot;
3. Short-range device-to-device communications;
4. Smart rail mobility;
5. Multi-sensory extended reality;
6. Industrial automation and robotics;
7. Autonomous mobility;
8. Connectivity in remote areas;
9. Other use cases.

[1] There is also an analysis of coding and waveforms that may be of some value in later work in ETHER.

KPI table copied from document:

KPI	5G	6G
Peak data rate	20 Gb/s	1 Tb/s
Experienced data rate	0.1 Gb/s	1 Gb/s
Peak spectral efficiency	30 b/s/Hz	60 b/s/Hz
Experienced spectral efficiency	0.3 b/s/Hz	3 b/s/Hz
Maximum bandwidth	1 GHz	100 GHz
Area traffic capacity	10 Mb/s/m^2	1 Gb/s/m^2
Connection density	10^6 devices/km^2	10^7 devices/km^2
Energy efficiency	not specified	1 Tb/J
Latency	1 ms	100 µs
Reliability	$1-10^{-5}$	$1-10^{-9}$
Jitter	not specified	1 µs
Mobility	500 km/h	1000 km/h

Figure A-0-3: 6G Flagship KPIs

Key finding: There are some similarities and overlap in use cases between this white paper and ETHER (for example smart rail and air-space communications).

Key finding: The KPI table comparing 5G and 6G KPIs may be applicable for some aspects of the use cases we are considering.

Table A-0-8: 6G Flagship drivers and UN SDGs review

6G Flagship	White paper on 6G drivers and the UN SDGs [9]
Use cases	Nothing explicitly defined
KVIs	Nothing explicitly defined however some development linking the UN SDGs to key values is discussed in its table 4-4
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Touched on when addressing technological challenges

Key finding: As this white paper notes at the start "The commercial launch of 6G communications systems and the United Nations' Sustainable Development Goals (UN SDGs) are both targeted for 2030" therefore it makes sense to align work to the UN SDGs where possible.

A.5 CHINA ACADEMY OF ICT (CAICT)

CAICT is a Chinese organisation looking at many aspects of ICT including support 6G developments. The white paper lists multiple well known Chinese brands as major contributors and it is felt important to gain an insight into their views.

Table A-0-9: CAICT 6G vision review

CAICT	White paper on 6G vision and candidate technologies [10]
Use cases	Yes, see below
KVIs	Nothing explicitly defined
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Section 4.6 defines "*Distributed Autonomous Network Architecture*" and the subsequent sections also describe network aspects
Satellite/NTN	Section 4.9 describes "*Integrated Terrestrial and Non-Terrestrial Network*" and section 5.4 describes "*Satellites Assist Cellular Terrestrial Networks to Achieve Full 6G Coverage*". It is noteworthy that some Chinese organisations are very active in NTN aspects at 3GPP

Use cases defined:

1. Immersive cloud extended reality (XR) – a broad virtual space;
2. Holographic communications – extremely immersive experience;
3. Sensory interconnection – fusion of all senses;
4. Intelligent interaction – interactions of feelings and thoughts;
5. Communication for sensing – extending the functions of converged communications;
6. Proliferation of intelligence – ubiquitous smart core;
7. Digital twins – digital mirror of the physical world;
8. Global seamless coverage – three-dimensional connections.

Key finding: Their use case 8 with its 3D connectivity aligns with ETHER. In general, this white paper is strongly supportive of integrating NTN into 6G.

A.6 EUROPEAN COMMISSION HEXA-X PROJECT

The European commission (EC) Hexa-x project is set up to be "*A flagship for 6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds*" – basically exploring the opportunities and defining the needs of 6G for the EC.

Co-funded by the European Union

Table A-0-10: Hexa-X 6G vision use cases and values review

EC HEXA-X	**D1.1 – 6G Vision, use cases and key societal values [11]** **D1.2 – Expanded 6G vision, use cases and societal values [12][2]**
Use cases	Six categories and twenty-nine use cases are defined
KVIs	A KVI and KPI methodology are detailed, and values defined for each category
KPIs	See above
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined though the architecture options are discussed
Satellite/NTN	Multiple mentions

The six use case categories are:

1. Sustainable development;
2. Massive twinning;
3. Immersive telepresence for enhanced interactions;
4. From robots to cobots;
5. Local trust zones for human and machine;
6. Enabling services harnessing new capabilities.

Key finding: The closest use case category to ETHER is the sustainable developments though aspects of massive twinning may align and their KVIs and KPIs may be relevant/

Key finding: The KVI and KPI methodology as illustrated in the deliverables and reproduced below should be considered for this deliverable.

[2] D1.2 is essentially an update to D1.1.

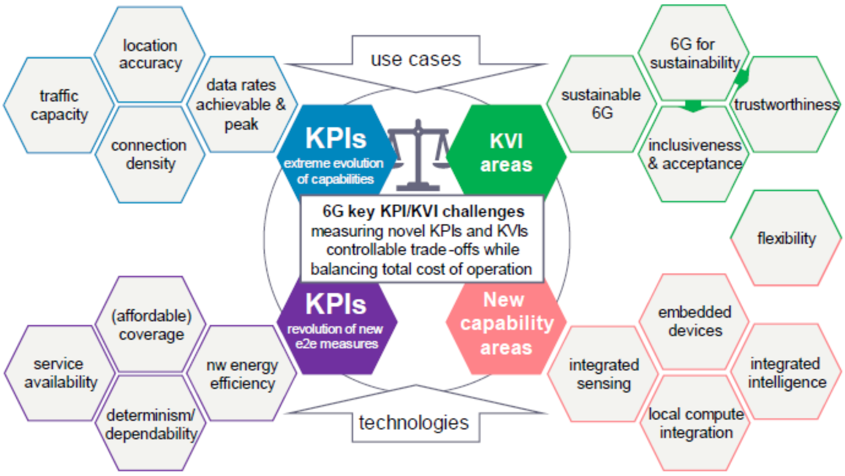

Figure A-0-4: Hexa-X KPIs KVIs and new capabilities

Table A-0-11: Hexa-X Requirements and architecture review

EC HEXA-X	D1.3 – Targets and requirements–for 6G – initial E2E architecture [13] D5.1 – Initial 6G Architectural Components and Enablers [14] D5.2 – Analysis of 6G architectural enablers' applicability and initial technological solutions [15]
Use cases	Updates on the use families
KVIs	Updates on the KVIs and methodology
KPIs	Updates on the KPIs, values, and methodology
Requirements	Nothing explicitly defined
Architectural guidelines	Eight architectural principles are introduced, and these are shown in the figure reproduced below from D1.3. D5.1 and D5.2 in particular
Satellite/NTN	Mentioned in context of flexible networks and campus networks; there is a whole section (4.3) in D5.2 on NTN and 3D networks

The eight architectural principles are shown below.

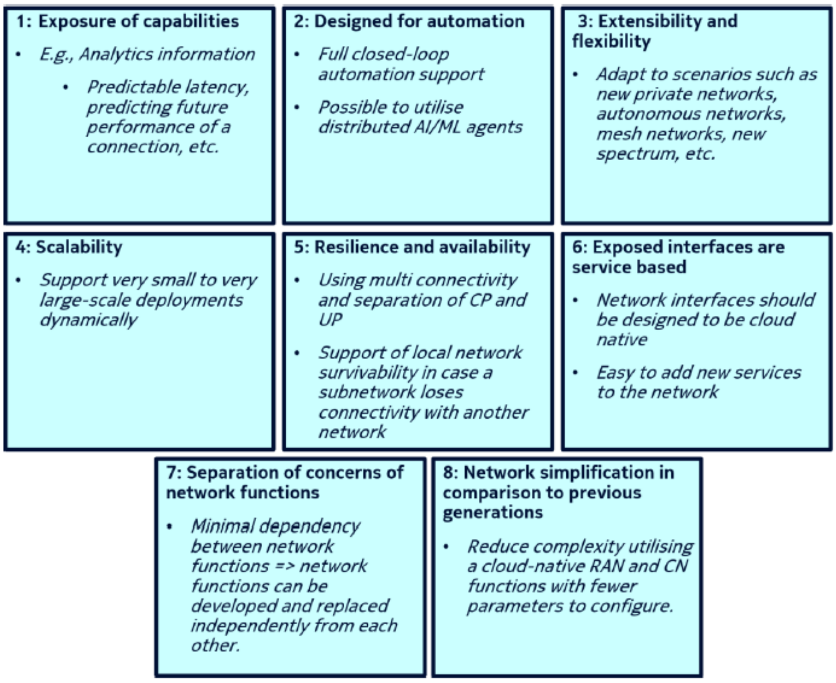

Figure A-0-5: Hexa-X architectural principles

Key finding: These architectural principles should be followed in ETHER.

Key finding: When considering the architecture in ETHER the work in D5.2 section 4.3 should be considered.

A.7 EUROPEAN SPACE AGENCY (ESA)

The European Space Agency (ESA) has been heavily involved for many years supporting projects looking at the convergence of satellite and terrestrial networks involving many organisations across its member states. One recent project is EAGER involving five partners plus ESA that has released a very relevant report by some of this sector's experts.

Table A-0-12: ESA NTN architecture and services review

ESA	Architectures, services, and technologies towards 6G non-terrestrial networks [16]
Use cases	Builds on 5G use cases with a modified IMT-2020 triangle (report figure 11 and reproduced below) using the satcom strengths to support service continuity, ubiquity, and scalability. It then adds an outer layer of additional uses families for 5G advanced and for 6G (report figure 12, also reproduced below).

ESA	**Architectures, services, and technologies towards 6G non-terrestrial networks [16]**
KVIs	Nothing explicitly defined, though a number of NTN characteristics that could be seen as key values are listed from page 33 et seq. of the report and are listed below
KPIs	Section 2.3 in the report defines some performance parameters
Requirements	Nothing explicitly defined
Architectural guidelines	Section 2.3 in the report describes their view on NTN system architecture evolution including analysis of both transparent and regenerative satellite payloads
Satellite/NTN	This is the theme of the report

The use cases are expressed in the following figure:

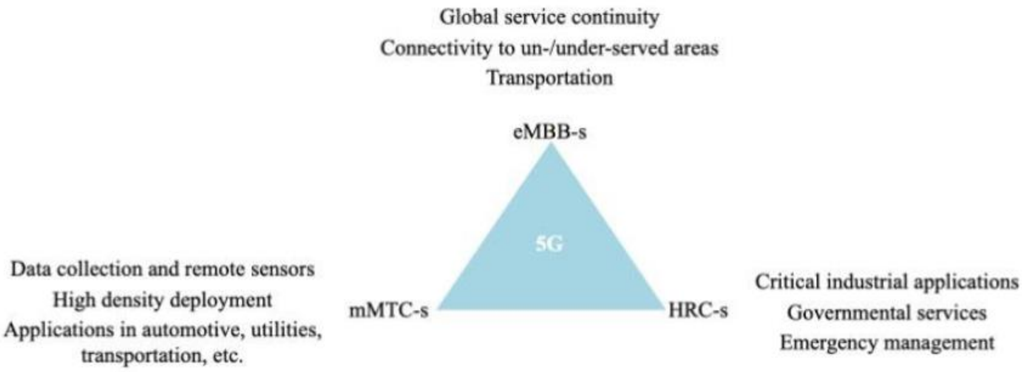

Figure A-6: ESA satellite use case family

The original source for this figure is not clear as it is also in an ITU report [51].

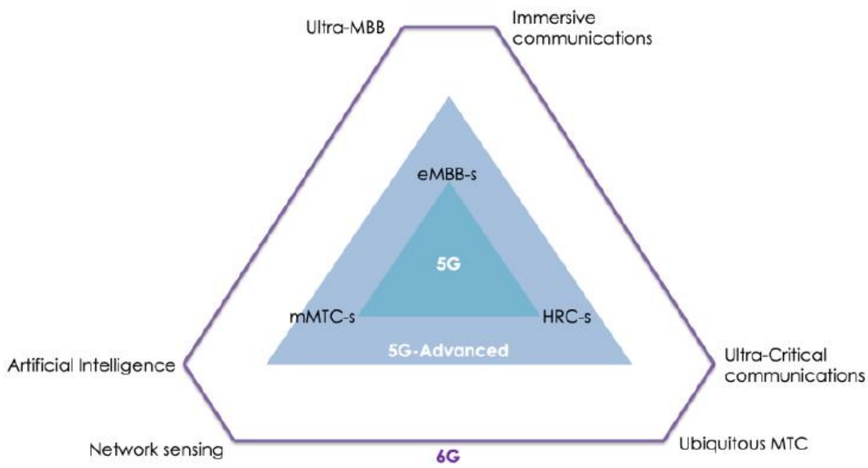

Figure A-7: ITU satellite use case family and 6G

The NTN characteristics that can be seen as key values defined are:

- Flexible allocation of the capacity to commensurate a varying traffic;
- Extended coverage towards global services;
- System sustainability;
- Network resiliency through massive redundant routing;
- Security;
- Service reliability through smart retransmission;
- Design to smart approach;
- Spectrum optimisation;
- Network infrastructure reconfigurability;
- Seamless response time through multi-connectivity between geostationary orbit (GSO) and non-GSO (NGSO).

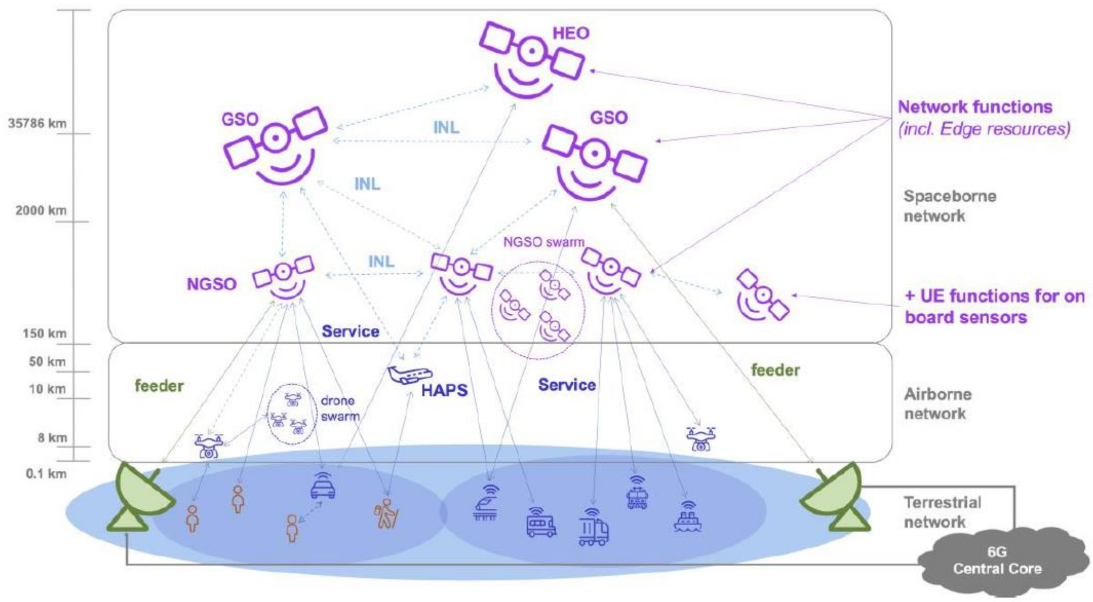

Figure A-8: ESA 3D network illustration

Key finding: This report has much good detail on standards and related aspects that should be carried forward into ETHER. In addition is definition of the -s use cases should be adopted.

Key finding: ETHER should build on the architectures defined in this report.

A.8 GLOBAL SATELLITE OPERATORS ASSOCIATION (GSOA)

GSOA is the global CEO-driven association representing satellite operators and provides thought-leadership and is recognised as the representative body for satellite operators by international, regional, and national bodies. It is the market representative body to 3GPP for the satellite sector. GSOA has produced a paper providing a vision for satellite communications in 6G.

Table A-0-13: GSOA 6G Vision

GSOA	Satellite communications and their role in enabling 6G [17]
Use cases	Yes; Global coverage, sustainability, reliability, resilience, security and authentication, meeting capacity requirements, positioning and timing.
KVIs	Key values defined as ubiquity, continuity, scalability, and resilience without adding any related KVIs.
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined though they have a good high-level concept image reproduced below.
Satellite/NTN	This is the theme of the report

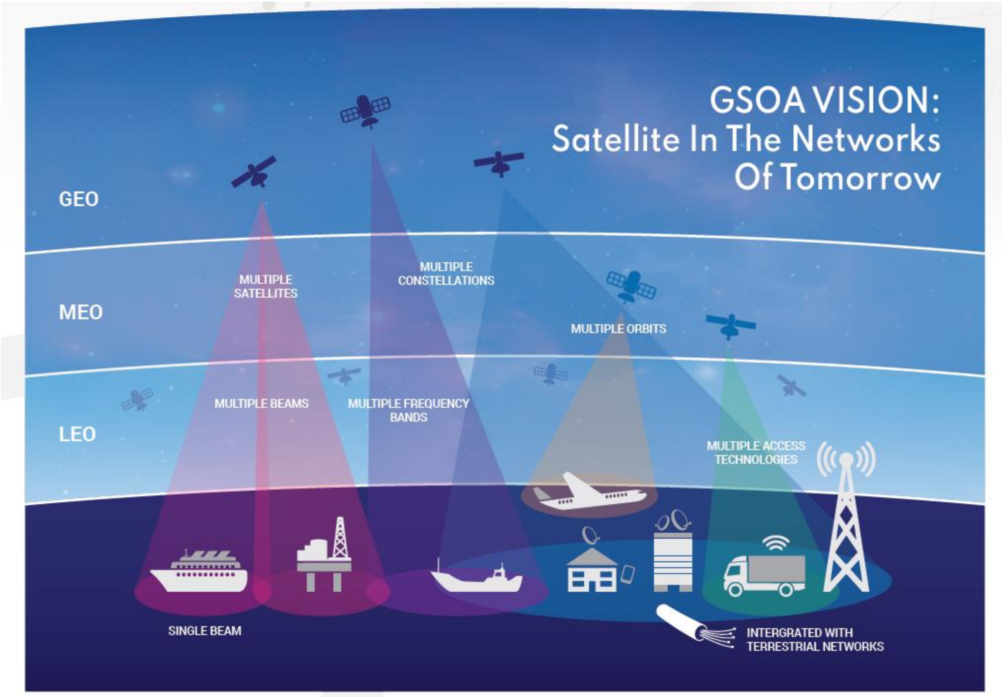

Figure A-0-9: GSOA satellite aspect of the 3D network vision

Key finding: The key values may be adopted in ETHER.

A.9 IEEE

The IEEE (Institute of Electrical and Electronics Engineers) is a professional association for electronics engineering, electrical engineering, and other related disciplines that amongst many other things produces standards such as for Ethernet and Wi-Fi. In recent years they have produced an annual roadmap for network generations that includes a section on NTNs, they are currently working on the fourth edition for 2023.

Table A-0-14: IEEE Future networks NTN roadmap review

IEEE	International network generations roadmap [18]
Use cases	The paper considers verticals along with associated drivers and enablers
KVIs	Refers to [8]
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Twelve reference architectures that they refer to as use cases are defined

IEEE	**International network generations roadmap [18]**
Satellite/NTN	This is the theme of the NTN chapter of the roadmap

Key finding: They provide a good overview of possible NTN architectures that may provide useful inputs to ETHER, similarly the key challenges may identify relevant topics.

A.10 ITU

The International Telecommunication Union (ITU) is the United Nations specialised agency for information and communication technologies. They write "*Founded in 1865 to facilitate international connectivity in communications networks, we allocate global radio spectrum and satellite orbits, develop the technical standards that ensure networks and technologies seamlessly interconnect, and strive to improve access to ICTs to underserved communities worldwide*". ETHER is not looking at spectrum related issues nor at orbital filings.

They provided the oft-quoted use case triangle for IMT-2020 (as they refer to 5G) in their IMT-2020 framework [19]. Of more relevance to ETHER, they are working on developing their defining vision for IMT-2030 (or more commonly 6G). There is a report and some emerging recommendations.

Beyond this, the IEEE report in a blog [52] that "*At its 44th meeting in June 2023, ITU-R WP 5D finalised development of a draft new Recommendation ITU-R M.[IMT.FRAMEWORK FOR 2030 AND BEYOND] on "Framework and overall objectives of the future development of IMT for 2030 and beyond." This draft recommendation is expected to be approved by year end 2023*", sadly too late for this deliverable.

Table A-0-15: ITU IMT2030 framework and objectives review

ITU	**ITU-R M.2083-0 IMT Vision – Framework and overall objectives of the future development of IMT for 2030 and beyond [19]**
Use cases	Discussed in the context of new services and drivers (immersive communications, massive communications, hyper-reliable & low latency communications, ubiquitous connectivity, integrated AI & communications, integrated sensing & communications)
KVIs	Nothing explicitly defined
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined though some aspects can be inferred
Architectural guidelines	Nothing explicitly defined though some aspects can be inferred
Satellite/NTN	Mentioned in context of coverage

Key finding: This is an important document as it sets out a direction for 6G however no specific inputs into ETHER are noted.

Table A-0-16: ITU further requirements review

ITU	**Rec. ITU-T Y.3200 Fixed, mobile and satellite convergence – Requirements for IMT-2020 networks and beyond [21]** **Recommendation ITU-T Y.3201 Fixed, mobile and satellite convergence – Framework for IMT-2020 networks and beyond [22]** **Rec. ITU-T Y.3202 Fixed, mobile and satellite convergence – Mobility management for IMT-2020 networks and beyond [23]** **Rec. ITU-T Y.3203 Fixed, mobile and satellite convergence – Connection management for IMT-2020 networks [24]**
Use cases	Y.3200 includes some scenarios showing both direct and indirect (backhaul) access and details four use cases in its appendix (Use case 1: Land-based network with low speed; Use case 2: Land-based network with low capacity; Use case 3: No land-based network of a specific operator; Use case 4: Disaster recovery) Y.3201 looks at differing deployment scenarios, Y.3023 looks at direct access UE to satellite (primarily NGSO, with GEO providing positioning service)
KVIs	Nothing explicitly defined
KPIs	Nothing explicitly defined
Requirements	Y.3200 provides some high-level requirements for service and for the NTN convergence
Architectural guidelines	Y.3200 provides very high-level system architecture Y.3201 provides direction on how 5GCN functions can be implemented on-board satellites.
Satellite/NTN	Yes

Note that Y.3201 requires the following about AI/ML in a mixed NTN-TN "*In the FMSC network, AI/ML is implemented in the aspects of enhancing mobility management, connection management, subscription management, policy control, capability exposure, network self-organising, and management and orchestration*".

Key finding: Rather high-level inputs that are already implied elsewhere but this ITU support is important.

A.11 NETWORLDEUROPE

NetworldEurope is "*the new incorporation of the European Technology Platform (ETP) for communications networks and services […] to follow the European changing policies as stated in Horizon Europe*". They provide direction on research and related societal issues to the EC.

One key output is the Strategic Research and Innovation Agenda (SRIA) that is issued annually. This document is divided in two large and related parts. The main body is a white paper that provides a high-level vision of their technological roadmap, The second part, the technical annex, provides a deeper reaching discussion on the technologies they envisage as key for the future of ICT.

Table A-0-17: NetworldEurope SRIA review

NetworldEurope	Strategic research and innovation agenda 2022 [25] SRIA technical annex [26]
Use cases	Nothing explicitly defined, they start from the precepts of a new architecture
KVIs	Nothing explicitly defined
KPIs	KPIs are discussed in the annex but not defined
Requirements	Nothing explicitly defined but reading through both documents many requirements can be derived.
Architectural guidelines	Multiple concepts are suggested
Satellite/NTN	A 3D network including NTN components is considered in both documents, for example illustrated in figure 7-1 of the main document and reproduced below; and chapter 8 of the annex focusses on NTN.

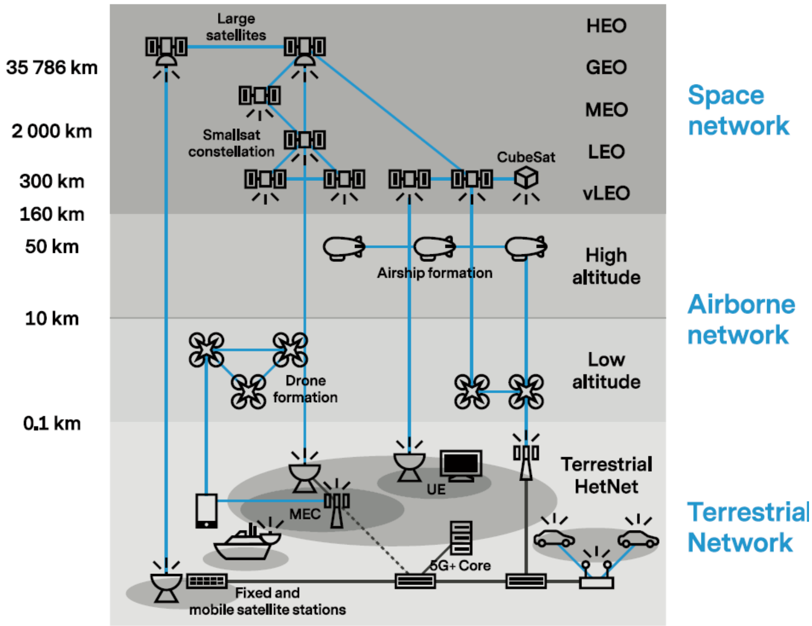

Figure A-0-10: NetworldEurope 3D network diagram

Key finding: The research areas identified may provide useful direction for ETHER research and innovation work.

Key finding: The KPIs considerations may also be relevant.

A.12 NEXT G ALLIANCE

The Next G Alliance is "*an initiative to advance North American wireless technology leadership over the next decade through private-sector-led efforts. With a strong emphasis on technology commercialisation, the work will encompass the full lifecycle of research and development, manufacturing, standardisation, and market readiness*".

Table A-0-18: Next G Alliance roadmap and use case review

NEXT G ALLIANCE	Roadmap to 6G [27] 6G applications and use cases [28]
Use cases	Four use case categories and sixteen use cases considered with no direct correlation to the ETHER use cases. The roadmap provides a good flow-down from the UN SDGs through issues
KVIs	Nothing explicitly defined, though the issues in the roadmap could be interpreted as key values.
KPIs	Some use cases have KPIs and the roadmap provides key performance objectives.

NEXT G ALLIANCE	**Roadmap to 6G [27]** **6G applications and use cases [28]**
Requirements	Most use cases have a few high-level requirements (perhaps more akin to KVIs)
Architectural guidelines	The roadmap considers network architecture in the technology enablers described in its section 7
Satellite/NTN	Repeated mentions for resilience/reliability and inclusivity in the Applications and Use Cases document and touched on in the roadmap

Key finding: The roadmap provides some insights in network architecture and research areas that the ETHER project may consider.

Key finding: Both documents provide useful material for key values and KPIs.

A.13 NGMN

The NGMN (Next Generation Mobile Networks) Alliance states that is has the vision to "*provide impactful guidance to achieve innovative and affordable mobile telecommunication services for the end user with a particular focus on supporting 5G's full implementation, Mastering the Route to Disaggregation, Sustainability and Green Networks, as well as 6G.*"

In [31] they provide a useful diagram (see below) that positions the three documents (this plus [30] and [29]).

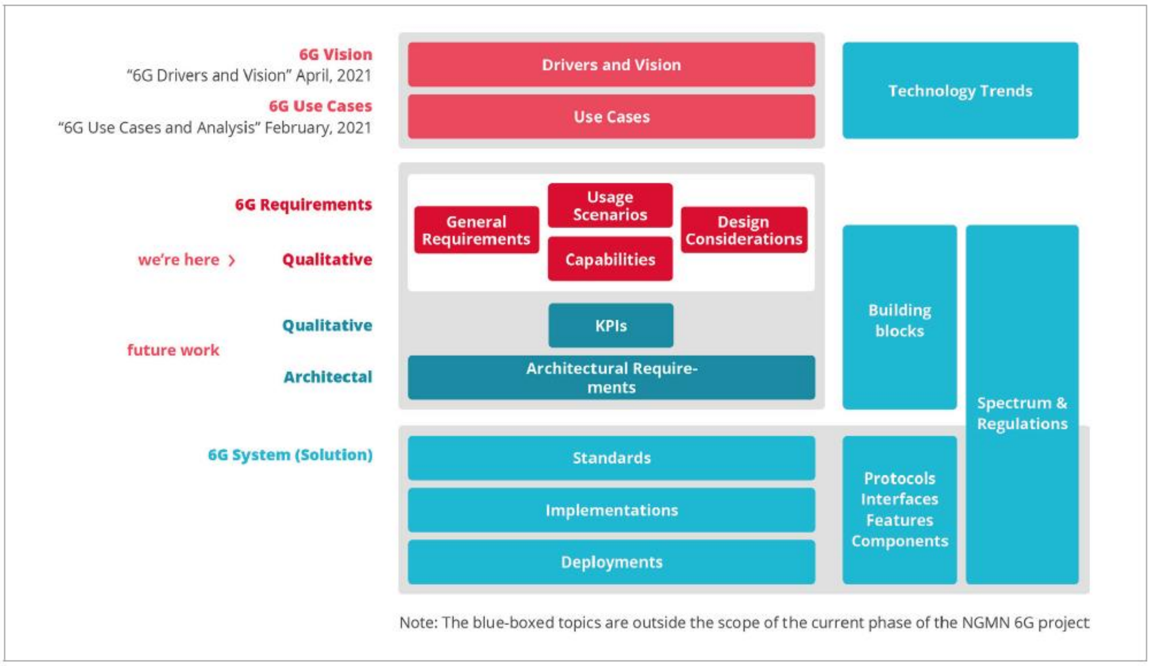

Figure A-11: NGMN showing how their documents relate to each other

Table A-0-19: NGMN use cases, drivers and requirements review

NGMN	**6G Use cases and analysis [29]** **6G Drivers and vision [30]** **6G Requirements and design considerations [31]**
Use cases	Four use case families and fourteen generic use cases are identified in [29] – appendix A provides a good template for considering use cases against the following criteria: • Synopsis; • Alignment with NGMN drivers; • High level requirements and spectrum; • Environmental impact including energy consumption; • Technology needs relative to 5G; • Impact on deployed 5G networks; • Feasibility; • Industry growth opportunity; • Disruptive impact.
KVIs	In [31] some key values are well described but are not enumerated
KPIs	No
Requirements	Yes, focussing largely on architecture with plans to add more details on other requirements in due course

NGMN	6G Use cases and analysis [29] 6G Drivers and vision [30] 6G Requirements and design considerations [31]
Architectural guidelines	Yes
Satellite/NTN	Yes, though limited

It is interesting to note that 3GPP refers to the use cases document on their website when mentioning the future direction towards 6G,

Key finding: Their method for detailing use cases provides a good reference for ETHER.

Key finding: The design considerations and trade-offs analysis may provide useful inputs to the ETHER architectural work.

Recently they provided a position statement offering an operator view on how 6G should be framed – they believe "*that 6G is the graceful evolution of communication networks into the 2030s, delivering compelling new services and capabilities for customers whilst maintaining essential offerings such as voice. 6G will build on, and extend beyond, our existing 5G ecosystem to foster new innovations which deliver value to customers and simplify network operation. Concurrent to this journey towards the 6G era is the development of network disaggregation and an open, interoperable cloud native architecture*".

Table A-0-20: NGMN 6G position statement review

NGMN	6G position statement – An operator view [32]
Use cases	No
KVIs	No
KPIs	No
Requirements	The guiding principles, and the operational priorities should be noted and respected when considering ETHER developments
Architectural guidelines	No
Satellite/NTN	No

Key finding: The guiding principles should be noted, especially "*2. 6G must not inherently trigger a hardware refresh of 5G RAN infrastructure*".

A.14 NICT

Japan's National Institute of Information and Communications Technology (NICT) is there "*sole National Research and Development Agency specialising in the field of information and communications technology, NICT is charged with promoting ICT sector as well as research and development in ICT, which drives economic growth and creates an affluent, safe and secure society*".

Table A-0-21: NICT white paper review

NICT	**Beyond 5G/6G white paper v2.0 [33]**
Use cases	Four somewhat "science fiction" scenarios are discussed to provide a far-sighted vision to consider the practical implications
KVIs	Nothing explicitly defined
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	In the context of multi-layering (i.e., 3D) networks.

Key finding: The key technologies may provide some useful inputs to key values.

A.15 ONE6G

one6G aims "*to evolve, test and promote next generation cellular and wireless technology-based communications solutions. By supporting global 6G research and standardisation efforts, the goal is to accelerate its adoption and overall market penetration, while addressing societal and industry-driven needs for enhanced connected mobility*". They have two relevant white papers.

Table A-0-22: One6G white papers review

One6G	**White paper, 6G vertical use cases [34]** **White paper, 6G technology overview – Second Edition [35]**
Use cases	The use case white paper identifies 25 vertically driven use cases with actors, pre-conditions, descriptions/service flows, and post conditions being detailed. None of these use cases is particularly similar to the ETHER use cases

One6G	**White paper, 6G vertical use cases [34]** **White paper, 6G technology overview – Second Edition [35]**
KVIs	Nothing explicitly defined
KPIs	Each use case has a discussion about the kinds of KPIs that might be needed but no actual values.
Requirements	The use case white paper identifies potential service requirements for each use case however there is no direct correlation between these and ETHER use cases.
Architectural guidelines	The technology overview has some thoughts on aspects that may impact on the 6G architecture.
Satellite/NTN	Mentioned for some use cases

Key finding: There is no direct correlation between their use cases and those in ETHER however their analysis methodology has merit and may be considered. Some of the use cases have some similarities that could perhaps be leveraged.

Key finding: The technologies considered especially when looking at what is needed beyond today's state-of-the-art may be useful in ETHER.

A.16 SK TELECOM

SK Telecom is a South Korean wireless telecommunications operator and former film distributor and is part of the SK Group, one of the country's largest. Their website suggests a major focus in the integration and provision of AI/ML services. This has been included to as no national document from South Korea has been identified.

Table A-0-23: SK Telecom use cases review

SK Telecom	**6G use cases [36]**
Use cases	These are addressed in passing whilst considering promising service prospects and technology trends.
KVIs	Nothing explicitly defined
KPIs	Nothing explicitly defined
Requirements	Some very high-level requirements are discussed
Architectural guidelines	Nothing explicitly defined, though they do express the need for simplicity to be able to deploy commercially

SK Telecom	**6G use cases [36]**
Satellite/NTN	Mentioned multiple times and well considered under the context of aerial networking

Key finding: Whilst no specific inputs may be directly applicable to ETHER, the general tone and excellent review from a market leading provider of 5G services is highly recommended reading.

A.17 TSDSI

The Telecommunications Standards Development Society, India (TSDSI) was set up in 2014 to "*create an Indian telecom SDO, for contributing to next generation telecom standards and drive the eco-system of IP creation in India*". Furthermore "*TSDSI is an autonomous, membership based, SDO for Telecom/ICT products and services in India*".

Table A-0-24: TSDSI use cases review

TSDSI	**6G use cases and enabling technologies [37]**
Use cases	Eight use cases are defined and are listed below
KVIs	Their vision has five items that can be seen as key values
KPIs	Nothing explicitly defined
Requirements	Nothing explicitly defined
Architectural guidelines	Nothing explicitly defined
Satellite/NTN	Stated to be one of eight key technology enablers for 6G

TSDSI use cases:

- Ubiquitous connectivity/compute experience
- Enabling smart villages/remote area accessibility including e-health and education
- Automated transportation
- Industrial Internet/tactile Internet
- Immersive interactive experience
- Supply chain and logistics
- Surveillance for industries and civic crime control
- Native AI and ML in networks

Key finding: There is no direct correlation between their use cases and those in ETHER, though the ubiquity cases are related.

A.18 OTHER AREAS LOOKED AT

The papers reviewed above represent many key global, regional, and major national bodies covering Europe, North America, and Asia. With the exception of Korea, papers by individual companies have not been included in this review in an attempt to make a balanced overview of where the world sees 6G heading rather than the views of individual organisations however influential they may be.

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