A holistic flagship towards the 6G network platform and system, to inspire digital transformation, for the world to act together in meeting needs in society and ecosystems with novel 6G services.

Deliverable D1.2
6G Use Cases and Requirements

Co-funded by the European Union

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Abstract

This report presents the Hexa-X-II set of use cases that aims to guide future research towards 6G within the project. These use cases have been analysed from a technical point of view but also from a sustainability point of view. The analysis includes the respective requirements and KPIs per use case. In addition, the channel models and business models applicable to these use cases have been studied, and the possible gaps have been identified.

Keywords

6G, Sustainability, Environment Sustainability, Social Sustainability, Economic Sustainability, Use Cases, Requirements, KPIs, 6G Design, Channel Models, Business Models

Disclaimer

Executive Summary

This report is the second deliverable of Work Package 1 (WP1) “6G Values and Requirements” and focuses on the new Hexa-X-II set of 6G use cases. These 6G use cases, requirements and KPIs represent the starting point for technology design and subsequent implementation.

On November 18th, 2023, the ITU-R agreed on the recommendations for the new “IMT-2030 Framework”, which lays the foundation for activities such as 6G development, standardization, and deployment. Nevertheless, research on 6G and especially on 6G use cases has been ongoing for some time already. In the past few years, different global and regional organizations have published their views regarding use cases and requirements for the next generation of mobile communications. All initiatives have pushed further the limits of current 5G capabilities in the areas of **enhanced mobile broadband (eMBB), ultra-reliable low latency communication (uRLLC)**, and **massive machine-type communication (mMTC)**. In addition, the use of **artificial intelligence (AI)/machine learning (ML)** and **sensing** capabilities is widely acknowledged, together with ensuring **network ubiquity**. Finally, new technologies and applications such as **immersive experiences (IEs)** and **digital twins (DTs)** are present across the different 6G use case initiatives.

Hexa-X-II’s new set of 6G use cases evolves and widens the initial set of use cases introduced in the first deliverable of WP1 “Environmental, social, and economic drivers and goals for 6G”. While Hexa-X-II use cases have shown a shared comprehension of the deployment of key technologies in the development of the 6G era (eMBB, uRLLC, mMTC, AI/ML, Sensing, IEs, DTs, Ubiquitous Networks) with the different regional initiatives addressed, sustainability has been approached differently. The Hexa-X-II project’s objective goes beyond by taking a comprehensive view on sustainability considering environmental, social, and economic aspects as the three key pillars of 6G use cases. Thus, Hexa-X-II has expanded beyond energy efficiency, by taking **a concrete and transparent approach to sustainability** (environmental, social, and economic) as a key element of the detailed analysis of all representative use cases. The inclusion of these three pillars is vital in light of the expected ubiquity of the 6G ecosystem, highlighting the importance of designing a value-oriented ecosystem. This deep dive will be further expanded in future deliverables of WP1, including sustainability assessment, risks, and mitigation strategies.

Subsequently, Hexa-X-II has identified six use case families aiming to embrace the need for 6G. The families are **Immersive Experience, Collaborative Robots, Physical Awareness, Digital Twins, Fully Connected World, and Trusted Environments**. For each family, a representative use case was selected displaying the key aspects of that family. The six representative use cases have undergone a detailed analysis from which the **requirements and KPIs** that will guide the research in the subsequent project stages (e.g. designing phase) were extracted. While being inspired by the capabilities introduced in the IMT2030 Framework, the KPI analyses presented in this deliverable are use case-specific and emphasize the end-to-end performance aspects. Accordingly, further differentiation and refinement of capabilities as well as iterations with the Hexa-X-II design phase are required before definitive KPI values can be finally delivered.

Additionally, a **channel model analysis** was performed. The most common and used channel models (statistical geometric and deterministic channel models) have been identified and studied. The analysis has shown that channel models will be able to cover most of the use cases outlined by Hexa-X-II. However, new capabilities such as sensing introduce the need for new channel models as well as model extensions for frequencies above 100GHz to cover the needs of some use cases.

Finally, **business models** were studied and applied to a selected subset of the representative use cases. These business models include revenue models, which is the ultimate goal of a use case, together with helping the reader to understand the **value propositions** of a use case’s business ecosystems and to specify **business opportunities** for single stakeholders. Further analysis of use cases will be expanded in future deliverables of WP1.

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Acronyms and Abbreviations

Acronym	Term
3D	Three Dimensional
3GPP	3rd Generation Partnership Project
5G-PPP	5G Infrastructure Public Private Partnership
6DoF	6-degrees-of-freedom
6G	Sixth-Generation Technology for Wireless Communications
A-GNSS	Assisted Global Navigation Satellite System
AGV	Automated Guided Vehicles
AI	Artificial Intelligence
API	Application Programming Interfaces
AR	Augmented Reality
ATIS	Alliance for Telecommunication Industry Solutions
B2B	Business to Business
B2C	Business to Consumer
BMC	Business Model Canvas
Cobots	Collaborative Robots
devices/m2	Number of devices per square metre
DT	Digital Twin
Dx.y	Deliverable 'y' from Work Package 'x'
E2E	End to End
eMBB	Enhanced Mobile Broadband
EU	European Union
Gb/s	Gigabits per second
GHG	Greenhouse Gas
HAPS	High Altitude Platform Stations
IC	Intelligent Components
ICT	Information and Communication Technology
IMT	International Mobile Telecommunications
IoT	Internet-of-things
IR	Infra-red
IT	Information Technologies
ITU	International Telecommunications Union
JCAS	Joint Communication and Sensing
KPI	Key Performance Indicator
KVIs	Key Value Indicators
LoS	Line of Sight
M&O	Management and Orchestration

M2H	Machine to Human
M2M	Machine to Machine
Mb/s	Megabits per second
Mb/s/m2	Megabits per second per square metre
MIMO	Multiple Input, Multiple Output
ML	Machine Learning
mMTC	Massive Machine-Type Communications
mmW	Milimetre Waves
MNO	Mobile Network Operator
MR	Mixed Reality
ms	Millisecond
NGA	Next Generation Alliance
NGMN	Next Generation Mobile Networks
NTN	Non-Terrestrial Networks
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research & Development
RIS	Reconfigurable Intelligent Surfaces
RT	Real Time
SCM	Spatial Channel Model
SDGs	Sustainable Development Goals
SNS JU	Smart Network and Services Joint Undertaking
TN	Terrestrial Networks
UE	User Equipment
UN	United Nations
uRLLC	Ultra-Reliable and Low-Latency
V2X	Vehicle to X
VR	Virtual Reality
VRU	Vulnerable Road Users
WP	Work Package
XR	Extended Reality
Y/N	Yes or No

1 Introduction

In general, the definition of a new technology, such as the sixth-generation technology for wireless communications (**6G**), starts with the definition of a well-defined group of **use cases**, **requirements**, and **Key Performance Indicators (KPIs)** that the technology aims to fulfil. To derive the right requirements and KPIs for a new technology, it is important to have a view of how it will be used, and consequently, what desired functions have to be provided. These requirements and KPIs represent the starting point for technology design and subsequent implementation.

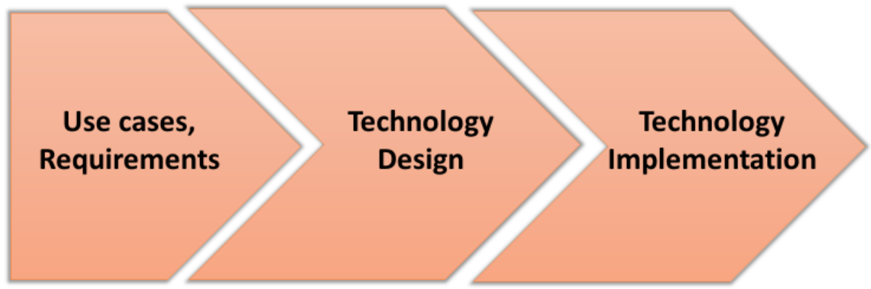

Figure 1-1: From use cases to technology implementation

The objective of Hexa-X-II is to create a **system blueprint** of a **sustainable, inclusive, and trustworthy 6G**, aiming at meeting the future needs of serving and transforming society and business. Overall, Hexa-X-II's objective was to deliver at least 50% of use cases with a significant positive effect on at least one dimension of sustainability (environmental, social, economic). However, this document will go beyond this initial goal, shifting to a comprehensive sustainability perspective addressing all three pillars. That is why all Hexa-X-II use cases include a sustainability analysis where the relation of each use case with its environmental, social, and economic impacts are identified.

1.1 Objective of the Document

This deliverable provides a comprehensive set of 6G Use Cases and Requirements which will lead the Hexa-X-II research work. The use cases presented here, are built on insights gained from the work done in D1.1 [HEX223-D11]. Consequently, this document continues the path with concrete scenarios and usages for the technology. Therefore, the deliverable includes a consolidated view of use cases and requirements for 6G, with scenarios for channel models, and first insights on the business and revenue models for the 6G ecosystem.

The next step in Work Package 1 (WP1) is to perform a deeper analysis of the challenges and risks in order to meet environmental, economic, and societal sustainability goals, with a first view on societal acceptance. This analysis will be accompanied by a Key Value Indicators (KVIs) analysis of the different use cases and a comprehensive view of the business ecosystem with the identification of key stakeholders. These outcomes will be published in the next Hexa-X-II deliverable (D1.3).

1.2 Structure of the Document

This document is structured as follows: Chapter 2 presents an analysis of the current State of the Art of 6G use cases worldwide, outlining the different approaches adopted by different key global research activities in 6G. Then, Chapter 3 will present the use cases developed within Hexa-X-II, together with the methodology and detailed analysis of the six representative use cases. Chapter 4 provides the state of the art and the conclusions when analysing the channel models for the use cases. Chapter 5 develops the business models for three of the representative use cases. Finally, conclusions are drawn in Chapter 6.

2 Use Cases: State of the Art

2.1 Introduction

This chapter sets out an initial analysis of the current State of the Art of 6G use cases. The chapter begins by outlining the International Mobile Telecommunications 2030 framework [M.2160-0] adopted and agreed upon by the International Telecommunication Union (ITU) in November, 2023. Then, the various approaches to use cases adopted by the different key worldwide activities in 6G are presented in the rest of the chapter. Finally, conclusions are drawn emphasizing the commonalities and the differences of the diverse approaches analysed.

2.2 IMT 2030 Framework: The Road to 6G

On November 18th, 2023, the ITU-R agreed on the recommendations for the new “IMT-2030 Framework” [IMT 2030]. This framework represents the starting point for developing technologies aiming to address the next generation of IMT standards.

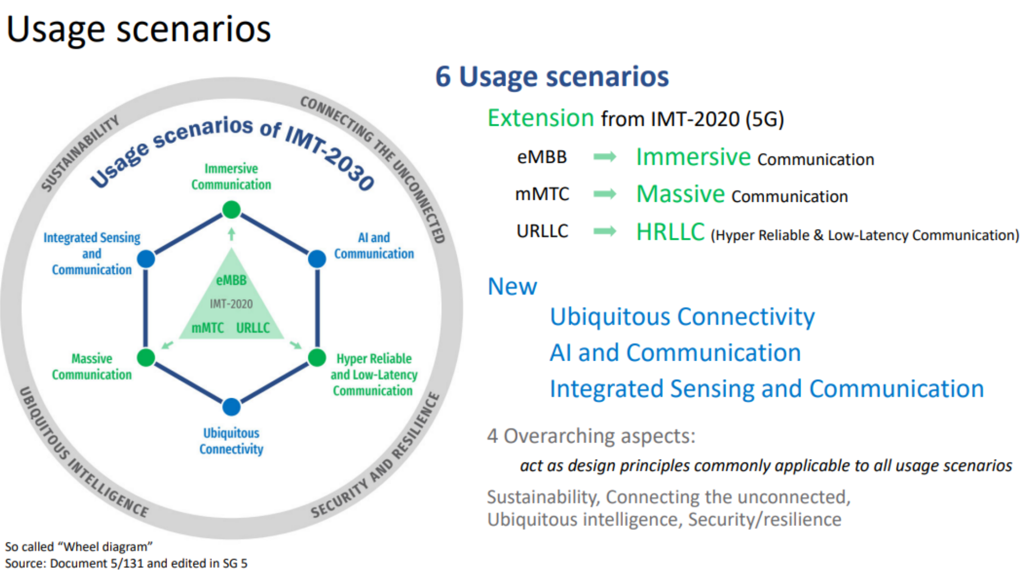

Figure 2-1: Usage Scenarios IMT 2030 Framework [M.2160-0]

In this framework, the ITU-R outline six “usage scenarios” for IMT-2030. Three of those scenarios, show an evolution from IMT-2020, i.e., Immersive Communication, Massive Communication, Hyper Reliable and Low-Latency Communication. The remaining three scenarios display new capabilities, namely Ubiquitous Connectivity, Artificial Intelligence (AI) and Communication, and Integrated Sensing and Communication. Furthermore, the six usage scenarios are supported by four “overarching aspects” or goals: sustainability, connecting the unconnected, ubiquitous intelligence, and security and resilience. The overarching aspects act as design principles and, therefore, are embedded in all of the usage scenarios.

In the following, a high-level description of the six usage scenarios is provided:

- *Immersive Communication* covers use cases which provide a rich and interactive video (immersive) experience to users, including interactions with machine interfaces.
- *Hyper Reliable and Low-Latency Communication* covers specialized use cases expected to have more stringent requirements on reliability and latency. These use cases typically focus on distributed applications that require tightly synchronised operations.

- *Massive Communication* focuses on connecting a massive amount of connected sensors and actuators for a wide range of use cases and applications.
- *Ubiquitous Connectivity* aims at enhancing connectivity to bridge the digital divide. Connectivity could be enhanced through interworking and convergence with other networks/systems.
- *Integrated AI and Communication* focuses on distributed computing capabilities and AI-powered applications. It enables unprecedented and specialized use cases by leveraging data collection, local or distributed compute offload, and the distributed training and inference of AI models across various intelligent nodes, such as transmission reception points (TRxPs) and devices in IMT-2030.
- *Integrated Sensing and Communication* facilitates new applications and services requiring sensing capabilities. Its goal is to offer wide-area multi-dimensional sensing that provides spatial information about unconnected objects as well as the movements and surroundings of connected devices.

2.3 Status of Key Worldwide Activities in 6G

In the last few years, different global and regional organizations have published their views regarding use cases and requirements for the next generation of mobile communications. Some of these organizations have been well-established for a long time, like the *Next Generation Mobile Networks Alliance* (NGMN) [NGM]. Others have emerged in different regions of the world or evolved from 5G research initiatives established earlier: *Smart Network and Services Joint Undertaking* (SNS JU) in Europe [SNS], the U.S.A. with Next Generation Alliance (NGA) [NGA] which is part of the Alliance for Telecommunication Industry Solutions (ATIS), China with the *IMT 2030(6G) Promotion Group*[IPG], Japan with the *Beyond 5G Promotion Consortium* [B5PC], South-Korea with *6G Forum* [6GF], and India with *Bharat 6G Alliance* (Bharat6G) [B6G]. All these initiatives comprise the key network operators, manufacturers, research institutes, and universities of the respective regions.

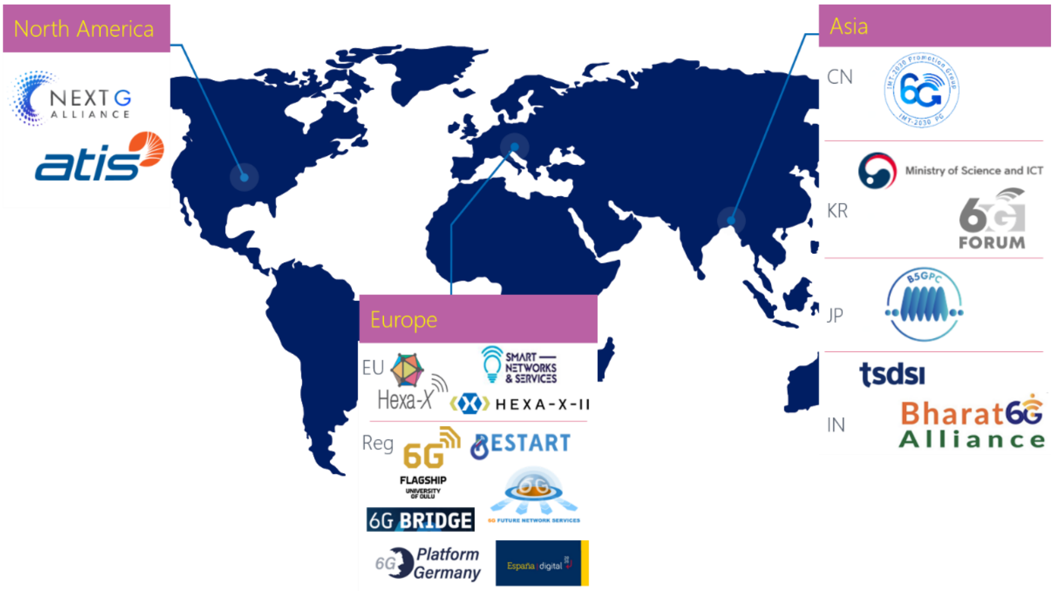

Figure 2-2: World map of key global activities in 6G

In the following sections, the diverse approaches to use cases adopted by these organizations are presented, starting with the NGMN alliance as a global movement, followed by the different regional approaches.

It is important to underline that this literature review was performed to the best of the author's knowledge with publicly available information. Accordingly, there might be initiatives that are not covered here. Also, the information related to the different key global activities presented here intends to depict the different approaches and key objectives. Consequently, the list is not exhaustive and should not be considered as such. For further details, the reader may refer to the original documents.

2.3.1 NGMN

The *Next Generation Mobile Networks* (NGMN) alliance announced the launch of a project on visions and drivers for 6G in October 2020 [NGM20] and released their first deliverable in April 2021 [NGM21]. More recently, the alliance published deliverables on 6G use cases and analysis [NGM22] and on 6G requirements and design considerations [NGM23]. In these deliverables NGMN has outlined four use case families based on their common characteristics: A brief description of the four use case families is provided in the following:

- *Enhanced Human Communication* includes use cases that have the potential to enrich human communications, such as immersive experience, telepresence, and multimodal interaction.
- *Enhanced Machine Communication* reflects the growth in the use of collaborative robotics, and autonomous machines, the requirement for sensing the surrounding environment and the need for robots to communicate among themselves and with humans.
- *Enabling Services* include use cases that require additional features such as high-accuracy location, mapping, environmental, or body sensing data.
- *Network Evolution* describes aspects related to the evolution of core technologies including AI as a service, energy efficiency, and delivering ubiquitous coverage.

Finally, NGMN highlights some of the main underlying drivers for these use cases, such as environmental impact and energy consumption, feasibility, industry growth opportunities, and impact on deployed 5G networks.

2.3.2 Europe

The *Hexa-X* [HEX21] flagship project was the first European-scale project offering a view of the research challenges beyond 5G. Hexa-X was one of the 5G-Infrastructure Public Private Partnership (5G-PPP) projects under the European Union's (EU) Horizon 2020 framework developed by *Smart Network and Services (SNS)*. The European SNS JU [SNS] is a public-private partnership that aims to facilitate and develop industrial leadership in Europe in 5G and 6G networks and services.

The project developed a 6G vision as an intelligent fabric of technology enablers connecting the human, physical, and digital worlds. Within [HEX21-D12], [HEX22-D13] and [HEX23-D14], Hexa-X defined and described 27 use cases focusing on the end-user perspective. These use cases were grouped into the following six families:

- *Telepresence*: The purpose of the use cases classified in the *Telepresence* use case family [HEX21-D12 - section 4.2.4] is the ability to be present anytime, anywhere. These use cases allow people to interact with each other as well as with the physical and digital items around them.
- *Robots to Cobots*: 6G might witness the generalization of collaborative robots (cobots) interacting and collaborating with humans in a shared area. Within the *Robots to cobots* use case family [HEX21-D12 - section 4.2.5] [HEX22-D13 - section 2.1.3], the focus is on the increased utilization of Artificial Intelligence (AI) and the potential of dependable communication [HEX21-D71] and collaboration among robots in both consumer and industrial use cases, either mobile or static, and humans.
- *Trusted Embedded Networks*: Many use cases of the *Trusted Embedded Networks* use case family [HEX22-D13 - section 2.1.5] require local or private communication capabilities for very sensitive information that is tightly integrated into wide-area networks. Trusted embedded networks can be dynamically reconfigured with autonomous and intelligent enabling of service capabilities to adjust to the type of network coverage required for the services.
- *Hyperconnected Resilient Networks Infrastructure*: 6G might cover different scales of networks: physical and virtualized, with different ranges, from very wide areas to local and very short-range networks. The *Hyperconnected Resilient Networks Infrastructure* use case family [HEX22-D13 - section

2.1.4] gathers different use cases building on this granularity, requiring a highly resilient infrastructure based on multiple networks, or networks of networks.

- *Massive Twinning*: An important aspect of most 6G use cases is the support for – and utilization of – Digital Twins (DT), a trend that is expected to gain significance in various domains. DT will gain more and more importance, being employed in a growing set of use cases, and this generalization of the application of DT is labelled as "massive twinning".
- *Enabling Sustainability*: While building on the sustainability gains of 5G, 6G should aim to be an asset for various sectors to reduce their environmental impacts and to create value for society.

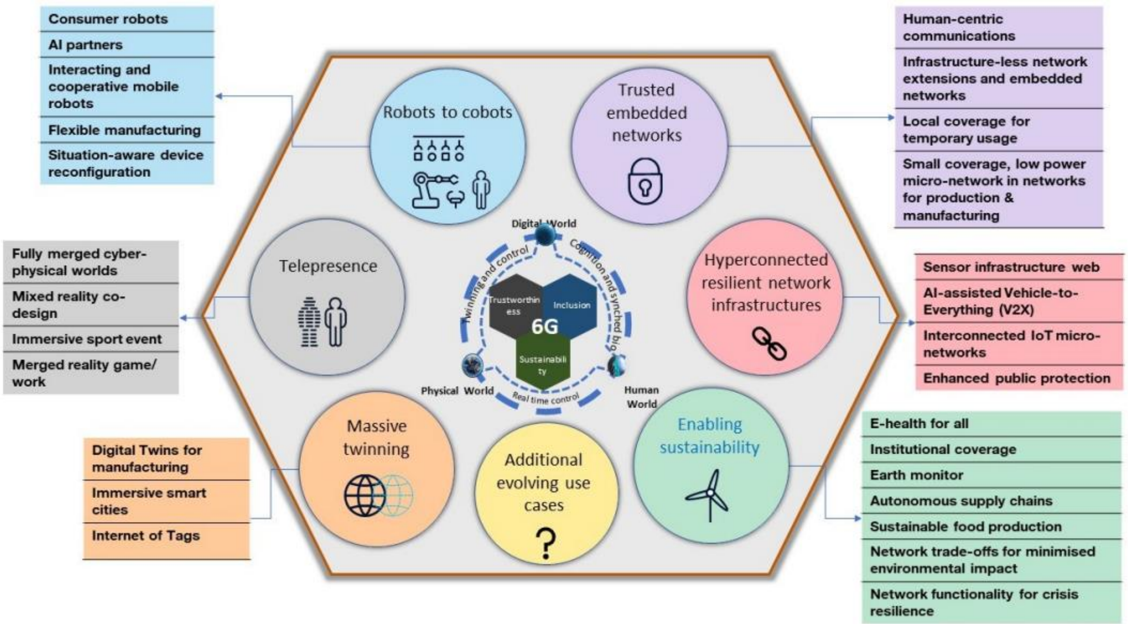

Figure 2-3: Hexa-X use cases

In addition to the different SNS JU activities, different European countries have started their own 6G Research program in the past years. Some initiatives are Germany's "*Platform for Future Communication Technologies and 6G*" (6G Platform) [6GP], Finland's "*The 6G Flagship*" [6GFl] and "*6G Bridge*" [6GB], Spain's "*España Digital 2026*" [ED26], Italy's "*Research and innovation on future Telecommunications systems and networks*" (Restart) [RES], and the Netherlands's "*Future Network and Services*" [FNS]. These initiatives are expected to provide use cases and requirements that ultimately complete the European vision of research on 6G.

2.3.3 United States

In their paper called "6G Applications and Use Cases" [NGA22], the "*Application Working Group*" of ATIS NGA analyses the drivers of future applications that have the potential to influence the development of 6G. These 6G applications are expected to improve the productivity, quality, time-to-market, and cost-effectiveness of companies. Four categories were identified:

- *Everyday Living*: 6G applications are expected to improve the quality of ordinary daily living. For example, service robots may provide health care, caregiving, indoor or local delivery services, and intelligent travel assistance.
- *Experience*: 6G applications target services in the area of Mixed Reality (MR) entertainment, human-machine interactions, health care (physical and psychological) assistance, real-time interactive gaming with physical interactions, classrooms powered with MR content, and robotics and eXtended Reality

(XR)-enriched Simultaneous Localization and Mapping-based applications such as in the transportation field.

- *Critical Roles*: Applications addressing critical roles are intended to improve the quality of technology in and around healthcare, manufacturing, agriculture, and public safety with the use of robotics.
- *Societal Goals*: It is expected that 6G applications will facilitate the achievement of high-level societal goals and increase public safety. Digital equity both access and benefits, reduced CO_2 emissions, energy efficiency, longer-lasting batteries, and zero-energy devices are some of the main topics mentioned.

Figure 2-4: ATIS NextGen use cases and applications.

2.3.4 China

The IMT-2030(6G) Promotion Group published the white paper "6G Usage Scenarios and Key Capabilities" [IPG23]. The paper identified four driving forces in the development of 6G: sustainable economic development, sustainable social development, sustainable environmental development, and technological innovation and development. The group then identified five usage scenarios. A brief description of these five usage scenarios is provided in the following:

- *Super Mobile Broadband*: An evolution of enhanced Mobile Broadband capabilities, whose objectives are not only providing a human-centric immersive communication experience but also achieving seamless coverage anywhere in the world.
- *Ubiquitous Machine Connection*: Expanding the boundaries of massive Machine-Type Communications (mMTC) where 6G will allow for diversified transmission rates (from low to high) in ubiquitous massive connection allowing a full variety of applications compared to mMTC in 5G.
- *Superlative Ultra-Reliable and Low-Latency Communications:* Enhancing 5G Ultra-Reliable and Low-Latency, where there is not only a demand for lower latency and higher reliability, but also for capabilities of medium and high-speed data transmission and ultra-high precision positioning.
- *Quality Guaranteed Network Artificial Intelligence*: New scenario where integrated communication and AI computing is provided to application services as well as to the entire communication system operations which require intelligent learning or inference.
- *Integrated Sensing and Communication*: The integration of sensing capabilities will provide enhanced capabilities such as high-precision positioning, environment reconstruction, imaging and recognition. These capabilities not only open the possibility of new services but also will help to improve the performance and efficiency of communications by being able to adapt and optimize radio resources in a changing environment.

Figure 2-5: IMT-2030 (6G) Promotion Group's usage scenarios [IPG23]

2.3.5 Japan

Japan's "Beyond 5G Promotion Consortium" latest version of the white paper "Message to the 2030s" [B5P2023] from March 2023 offers a different analysis perspective. Instead of focusing on use case families to build use cases, as other initiatives have done, this document builds on market trends in key industries. While all these industries require digitalization and the power of modern mobile systems, the current state of digitalization and use of mobile systems varies by industry. The industries analysed were:

- Finance
- Aviation
- Construction and Real Estate
- Logistics and Transportation
- Telecommunication and IT
- Services, Public Services, Corporate Services
- Automotive
- Machinery
- Restaurant
- Entertainment and leisure
- Academic and other
- Electronics, precision electronics, and semiconductors
- Media
- Robots
- Shipbuilding
- Agriculture, fisheries, food, lifestyle-related
- Energy, resources, and materials

Based on the needs of each industry, a set of use cases is proposed from where their respective requirements are extracted. These requirements have been compiled and are presented below.

- *Mission Critical Communication:* This usage scenario refers to those use cases which require very stringent transmission reliability and latency characteristics. Examples of use cases belonging to this family are remote surgeries, driverless control systems for railways and automobiles, and full industrial automation.
- *Ultra Massive Connection*: Expanding on 5G scenarios, this usage scenario aims at enabling the handling of a large amount of devices for sensing and measuring purposes. This does not only refer to sensing the environment but also aims at handling a large amount of in-body devices.
- *Ultra-Broadband Communication*: This scenario expands on 5G requirements by providing extremely high data rates and low latency to support applications such as holographic communications, immersive experiences, and remote surgery in urban areas, while also expanding to other underserved locations (e.g., aircraft, roads).
- *Universal Coverage***:** This scenario refers to providing universal coverage, not only in land urban, rural, indoor, and outdoor, but also over water and in the airspace. Apart from providing coverage and enabling

of different use cases everywhere, universal coverage helps in providing resilience in case of natural disasters.

- *Ubiquitous Sensing*: This requirement refers to technologies that integrate sensing with communication systems. Some capabilities required are advanced localization, positioning, tracking, and mapping which can be useful for automotive driving, warehouse management, or automatic construction.
- *Intelligent Connection*: This requirement relates to incorporating AI capabilities into the networks and into applications. Examples of use cases are zero-touch operations, enhancing predictability for systems, inference for collaborative robots, and distributed learning.

2.3.6 South-Korea

The Korean government has announced a 6G R&D strategy with the ambition to achieve the "World's first 6G commercialization" [MSI23]. It started national R&D projects in August 2020, planning for technology trials in 2026 to launch commercial service in 2028. A long-term network strategy called the "*KNetwork 2030 Strategy"* was announced in February 2023 by the Korean government to utilize next-generation networks such as 6G, satellite, open Local Area Networks, and quantum communication, and to secure the world's best 6G technology.

Unlike other regional initiatives' approaches related to use cases, and similar to Japan's initiative, the South Korean government's approach is not explained through a set of use cases but rather by depicting the future ecosystem and the key topics their research will address. These are divided into five main categories, and three cross-cutting principles described below.

- *Wireless Communication*: Keen focus on the development of the upper-mid frequency band (7~24 GHz) aiming to overcome the capacity limitations of 5G in the 3.5 GHz range and the coverage limitations in the 28 GHz range. An example of such is the development of Extreme Massive MIMO (Multiple Input, Multiple Output) antennas and Integrated Circuit chips for controlling its components.
- *Mobile-core*: The focus is on developing software-centric network technologies to adapt to the transition from hardware-centric to cloud and software-driven communication networks. Additionally, AI-based mobile network technology for autonomous network management and service quality control will also be studied.
- *Wired-Network*: Aimed at not only making improvements in the wireless network segment but also in the wired network to enhance overall network performance. Research will focus on high-speed and high-capacity optical transmission systems and component technologies for the segment spanning from 6G front-haul to the backhaul and transport network. Reducing communication latency in these segments is crucial for enabling ultra-realistic and ultra-resolution services.
- *6G Systems*: The goal is to secure technology for quality control to realize seamless interoperation between the wireless, wired, and mobile-core networks segments connecting the end-user device to 6G-integrated services. With the expected commercialisation of 6G, various 6G-integrated services, such as urban air mobility and virtual reality, will emerge. For these, AI capabilities are expected to be used for distributing and interconnecting the resources, to ensure service-specific performance.
- *6G Standardization*: Ensure the compatibility of developed 6G technologies with international standards.

Finally, the government will put **safety and trustworthiness first** throughout all Research and Development (R&D) areas (e.g., wireless/wired communication, mobile-core, systems). Also, investments will be made in developing **energy-efficient** solutions for achieving higher performance with low-power input, and ultimately in responding to the global demand for carbon neutrality.

2.3.7 India

The Telecommunications Standards Development Society, India (TSDSI) outlines in their white paper on India's 6G vision [TSD22] four main goals for 6G: facilitate a ubiquitous intelligent mobile connected society, bridge the digital divide of the society, personalize and localize services, and provide native support for data ownerships and hierarchies. Furthermore, this paper introduced a list of the priority use cases for the country:

- *Ubiquitous Connectivity/Compute Experience*: Including collaborative network/compute entities assisted by semantic interoperability interfaces allowing for the integration of smart city platforms, macro networks, private networks, cyber-physical entities, private verticals, aerial network/compute entities and possible intermediaries.
- *Enabling Smart Village/Remote Area Accessibility Including e-Health and Education*: Introducing among others remote medical assistance for humans & farm animals, dynamic weather monitoring and warning systems.
- *Automated Transportation*: Enabling guided automated road use cases and transportation mechanisms, aiming to improve safety, relieve congestion, and increase speeds for intercity travel.
- *Industrial Internet*: Where ultra-low end-to-end communication latencies and hyperreliability are key use case features.
- *Immersive Interactive Experience*: Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) experiences aiming at entertainment, medicine, science, education, and manufacturing industries.
- *Supply Chain and Logistics*: With a high need for ultra-low indoor or outdoor positioning latencies for real-time tracking.
- *Surveillance for Industries and Civic Crime Control*: Enabling crowd management and AI/Machine Learning (ML)-based crime prevention.
- *Native AI and ML in Networks*: Use cases for both local AI at the device and AI in the network.

Additionally, in March 2023, India's Ministry of Communications released the "Bharat 6G Vision" [B6G23]. Unlike the previous document, this one does not focus on use cases but rather sets a plan for 6G research topics. Capabilities such as low latency, high bit rate, use of VR/AR, AI, Mobile Edge Computing, and Machine to Machine (M2M)/Machine to Human (M2H) interactions are identified as priorities. Moreover, achieving ubiquitous connectivity is highlighted as one of the key goals, which considers the integration with non-terrestrial networks, for it is an enabler for various use cases as well as bridging the urban/rural divide. Finally, sustainability is addressed with a clear focus on reducing the carbon footprint though also acknowledging economic and social aspects.

2.4 Summary and Analysis

In this chapter, a high-level overview of different global organisations' views regarding use cases and requirements for the next generation of mobile communications was presented. The summary and analysis of the key points are presented below.

Extreme Communication Requirements

First, all initiatives have further pushed the limits of current 5G capabilities. That is **enhanced mobile broadband (eMBB), ultra-reliable low latency communication (uRLLC), and massive machine-type communication (mMTC)**. In 6G, these capabilities not only aim at further pushing the limits within their dimensions but are also key enablers for the new features of the 6G technology.

Also, all initiatives have acknowledged the need for **ubiquitous coverage**, both indoor and outdoor. First, indoor scenarios are mostly aimed at supporting sensing capabilities as well as allowing the construction of digital twins. Second, a key concept found throughout the documents for enabling ubiquitous coverage related to outdoor environments is the use of non-terrestrial networks (NTN) to create a seamless ecosystem. The exact application for the global coverage varies across the documents, finding examples aimed at people or Internet-of-Things (IoT) devices. Another variation is related to whether the coverage is purely terrestrial or three-dimensional (3D), including sea, aircraft, and space.

New Capabilities

Second, the use of **Artificial Intelligence (AI)** and **Machine Learning (ML)** capabilities is widely present throughout the documents assessed, and it is one of the key novelties in the development of 6G. These capabilities are widely considered, whether it is for optimizing the performance of the network, enabling new applications and tools, or simply delivering pervasive intelligence to all processes. AI/ML is strongly embedded in the design of 6G.

Additionally, many use cases refer to the use of robots, for both residential and industrial use. A few initiatives present the use of robots as support/aid for daily life in healthcare-related use cases, or as transport of goods by drones or vehicles. In industrial settings, robots are utilized for efficiency purposes or for replacement of humans in risky scenarios. Irrespective of the sector, the 6G capabilities required converge in the use of **sensing** capabilities, precise **positioning/tracking**, and **AI orchestration**.

Technologies

Third, new technologies and applications are common between the different initiatives. There is a consensus throughout these organisations about the key role that **immersive experiences**, and therefore the use of VR, AR, and MR devices, will play in the 6G era. Although the use case applications may vary, these capabilities are among the few ones that are mostly aimed at the mass market.

Also, the use of **digital twins (DT)** is fully embedded in many use cases, across the different documents, and plays a key and collaborative role with several of the aforementioned capabilities.

Sustainability

Finally, **sustainability** has also been a concept widely mentioned across all documents. However, this is where the most diverse approaches are identified. The importance of energy efficiency and CO2 footprint reduction is often stated, with the latter commonly proposed through deploying more efficient hardware and benefiting from AI network orchestration. While some organisations highlight the importance of addressing some of the sustainability challenges, such as digital inclusion and resource depletion, broader aspects of sustainability i.e., social, economic, and environmental aspects are rarely identified. Thus, there is room for improvement justifying the Hexa-X-II’s ambition to design a sustainable and value-driven technology.

3 Hexa-X-II Use Cases

3.1 Introduction

In the Hexa-X-II deliverable D1.1 [HEX223-D11] an initial set of use cases based on Hexa-X [HEX21-D13] has been introduced. The Hexa-X use cases were selected to represent real-life applications of the physical, human, and digital worlds that apply to one or more verticals. In addition, Hexa-X targeted three core values: trustworthiness as a backbone for society, digital inclusion, and environmental sustainability for a global positive impact with respect to the United Nations (UN) Sustainable Development Goals (SDGs) [SDG].

The Hexa-X-II project's objective is to go beyond Hexa-X by taking a comprehensive view on sustainability considering environmental, social, as well as economic aspects as the three pillars of 6G use cases:

- **Environmental Sustainability**, contributing to the preservation of natural resources and ecosystem, as well as curbing climate change,
- **Social Sustainability**, aiming at the well-being of all individuals and communities with inclusion and trustworthiness being two key values, and
- **Economic Sustainability**, targeting long-term economic growth while respecting the environmental and social sustainability objectives.

It is undeniable that not all observed 6G drivers derive from clearly defined sustainability goals but rather originate from technology requirements and business demands. In Hexa-X-II all use cases will be evaluated based on the three pillars of sustainability looking both at potential benefits and at any unintended negative consequences which need to be understood to develop mitigation strategies. The initial sustainability analysis presented in this chapter will be complemented in future deliverables with an elaborate in-depth analysis, the introduction of sustainability challenges, risk analysis, mitigation strategies, and the development of KVIs.

This chapter is entirely dedicated to the presentation and analysis of the use cases identified as Hexa-X-II use cases. Section 3.2 introduces the methodology implemented for the analysis of Hexa-X-II use cases. Section 3.3 explains the relationship of this analysis with the IMT-2030 Framework. Section 3.4 presents the new use case families, and the remaining sections provide an analysis of representative use cases of the Hexa-X-II use case families.

3.2 Methodology

As outlined in the Hexa-X-II deliverable D1.1 [HEX223-D11] an enhanced analysis of 6G use cases is performed that is anchored in a deep understanding of the specific problems to be solved, the limitations of the current technologies, and the use of innovative capabilities to create appetite for new 6G services from the early days of 6G deployment. To select a comprehensive set of Hexa-X-II use cases, relevant to instruct the development of the 6G system, and to perform an enhanced analysis, this methodology aims at answering three key questions already identified in Section 6.6 of [HEX223-D11]:

1. What end-user problem and need are we addressing?
2. Why are current technologies not enough to solve the problem?
3. What innovations should 6G bring?

For this purpose, a use case structure has been designed and applied to the representative use cases of each family. Its format comprises five parts: (1) *use case description*, (2) *sustainability analysis*, (3) *service scenarios*, (4) *deployment aspects*, and (5) *requirements and KPIs*.

Part 1 "*Use Case Description*" presents the use case details and its context. This part contains an analysis of why 6G is needed. It offers solutions to the problems addressed by the use case and to the related challenges, thereby answering questions 1 and 2 listed above.

Part 2 "*Sustainability Analysis*" provides a qualitative analysis by outlining the key values and hence the potential effects relevant to a use case. These effects are grouped by benefits as "*sustainability handprints"* and cost as "*sustainability footprints*":

- **Sustainability Footprints:** In the context of Hexa-X-II, the term "footprint" is defined in alignment with ITU-T L.1480 [L1480], encompassing direct, i.e., first-order negative environmental effects, extended to direct negative social and economic effects. Furthermore, the Hexa-X-II definition of sustainability footprints includes second-order and higher-order environmental, social, and economic negative effects.
- **Sustainability Handprints:** In the context of Hexa-X-II, the term "handprints" refers to the positive effects enabled by a 6G-enabled solution. These encompass positive first-order, second-order, and higher-order environmental, social, and economic effects that do not only help mitigate and reduce direct negative effects but also generate additional positive contributions to the environment, society, and economy [Nor13].

In this deliverable, only first and second-order effects will be covered. Due to the complexity of social, economic, and ecological systems, due to infeasible predictability and uncertainty, higher-order effects can take many paths and may be subject to rebound effects and other externalities not considered in D1.2 but in future Hexa-X-II deliverables.

Additionally, most handprints and footprints depend on the final use that people will give to the technology. Therefore, the impacts listed emerge from the foreseeable potential usage scenarios that the proposed use cases will enable. Finally, it is important to underline that the social sustainability's potential footprints consider a scenario where no additional policies or legislations for a smooth transition to the new technologies are put in place, nor other tools to prevent and minimise any misuse of the technology. Appropriate mitigation strategies will be suggested in future deliverables.

The technology analysis structure of the use case format, in particular, Part 3 "*Example Service Scenarios*" and Part 4 "*Deployment Aspects*", allows the reader to understand service scenarios and the role that the 6G system will play in a use case.

Finally, all these parts represent the necessary steps to be taken to derive the requirements and KPIs presented in Part 5 "*Requirements and KPIs*". Ultimately, Part 5 will also guide us to identify what innovations 6G shall provide to enable a use case

3.3 Relation to IMT-2030 Framework

This section explains how the Hexa-X-II use case analysis of requirements and KPIs is related to the IMT-2030 Framework already introduced in Section 2.2. A discussion from an air interface perspective is given in [HEX223-D42].

The use case **requirements**, presented in Part 5, consider application and system aspects as well as end-to-end (E2E) requirements. These requirements are general and often not directly related to the IMT-2030 Framework.

Conversely, the **KPIs** of the use case, also provided in Part 5, are primarily inspired by the capability definitions provided by the IMT-2030 Framework. A key difference to the IMT-2030 definitions is that in general, E2E aspects and capabilities are looked at whereas IMT-2030 mostly focuses on the air interface. It is also important to note that IMT-2030 capability-related KPI values are specified as "research target" while "other values may also be explored and considered accordingly". The KPIs derived in this chapter are E2E KPIs as well as use case-specific and may require refinements and capability differentiation within and beyond this deliverable.

Table 3-1 provides a high-level comparison between the capabilities as defined in [IMT2030] and as applied here.

	IMT-2030	Hexa-X-II D1.2
1	Peak Data Rate	Not used in this document
2	User-Experienced Data Rate	User-experienced data rate
3	Spectrum Efficiency	Not used in this document
4	Area Traffic Capacity	Area traffic capacity
5	Connection Density	Connection density
6	Mobility	Mobility
7	Latency	End-to-end latency
8	Reliability	Reliability and availability
9	Coverage	Service coverage
10	Positioning	Positioning and location accuracy
11	Sensing-related Capabilities	Sensing-related capabilities; see below
12	Applicable AI/ML-related Capabilities	AI/ML-related capabilities; see below
13	Security and Resilience	Covered in paragraph "requirements" in section "requirements and KPI" of representative use cases
14	Sustainability	Covered in the "sustainability analysis" section of the representative use cases
15	Interoperability	Not used in this document

Table 3-1: Mapping of capabilities with IMT-2030 Framework

As can be seen in the table, peak data rate and spectrum efficiency are not used in this document, as both refer to the air interface, whereas this document covers use cases from an E2E perspective. Both capabilities can be derived from the actual air interface design based on user-experienced data rate, connection density, etc., and the deployment characteristics. Latency refers to E2E latency in this document, as seen on application level. Coverage is considered as service coverage beyond pure propagation or cell-edge link budget considerations. Interoperability is a requirement for all use cases.

As the IMT-2030 capability-related KPI values are formulated at an early point in time and derived from theoretical analysis and simulations, real deployments may not always fulfil these requirements. In the end, use cases are only meaningful if they can be delivered with acceptable cost and sustainability footprint. The feasibility of such use cases in an environmentally, socially, and economically sustainable way still needs to be evaluated within as well as beyond this project.

Sensing- and AI/ML-related capabilities are more detailed in the following, as both are new paradigms applied to current cellular systems.

Sensing-related capabilities

Network-based parameter estimation means extracting information, beyond decoding the data, from signals received in the radio interface. This involves the estimation of distance and angle to an object (localization) and the estimation of velocity and shape. Localization of connected objects (devices) is referred to as **network positioning** or just **positioning**, which is a well-established method in networks. Estimating parameters, i.e., position, velocity, or shape, for unconnected objects is termed **network sensing** or just **sensing**, which is a new area of investigation. Both methods may involve any infrastructure node or device within the network.

Beyond these network-based methods, devices may also be equipped with further sensors that perform positioning, i.e., localization of the device, and sensing for estimating parameters for objects, such as GNSS-receivers or lidars. Such **connected sensors** can feed data into a **sensor fusion** processing together with the network-based data.

AI/ML-related capabilities

The rise of AI/ML has already impacted 5G with the network wireless data analytics function, AI/ML for self-organizing networks, minimization of drive tests, and selected air interface optimizations. Furthermore, the management of the complete life cycle of AI/ML models including training, emulation, deployment, and inference is considered for 5G-Advanced standardization. Three types of AI/ML-related capabilities are distinguished in this document.

AI-Native: AI built into the 6G system to directly optimize communication, at the cellular protocol stack level or E2E, and to provide and optimize "beyond communication services" such as joint communication and sensing.

Embedded AI: Application-level AI solutions local to a 6G system node, e.g., local to the User Equipment (UE), or a network core functionality.

AI/ML provided by the network: The 6G network exposes AI/ML capabilities toward services running on top for increased efficiency and performance.

3.4 Hexa-X-II Use Case Families

Evolving the methodology of Hexa-X, an initial set of Hexa-X-II use cases selected from Hexa-X has been presented in the Hexa-X-II deliverable D1.1 [HEX223-D11]. A large collection of additional, new use case proposals has widened the scope considerably. The set union of Hexa-X and Hexa-X-II use cases has also provided a great amount of information and additional detail and has motivated revisiting and enhancing the Hexa-X use case families (Figure 3-1).

In each of the six use case families, the use case best representing the key aspects of the family and providing the basis for many, if not all, use cases of the family has been selected as the **representative use case**. The six representative use cases are subject to a detailed analysis following the methodology presented in Section 3.2. All other use cases are presented and described as well though at a lower level of detail.

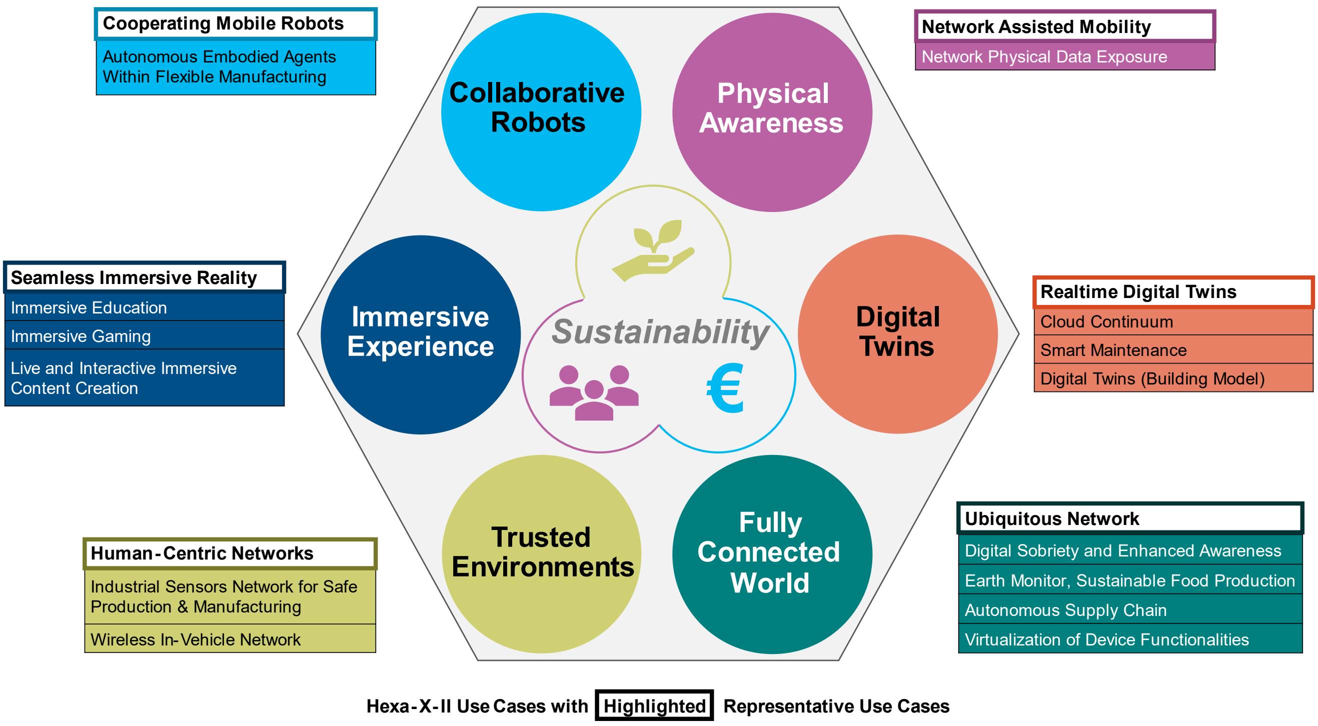

Figure 3-1: Hexa-X-II Use Case Families and Use Cases.

Accordingly, Hexa-X-II has identified six use case families:

- **Immersive Experience**: The immersive experience use case family comprises use cases based on the evolving technology of XR. Immersive experience is all about meeting the fundamental human need of "experiencing" a now digitally extended or virtual environment to understand and to act. This is enabled firstly by XR equipment stimulating 3D visual perception, spatial hearing, as well as haptics, and secondly by communicating and synchronizing data streams such that multiple participants have a consistent immersive impression. The use cases of this family capture immersive telepresence, immersive experience in collaboration, education, real-time gaming, and creation of immersive content.

- **Collaborative Robots**: The collaborative robots family includes several use cases for intelligent, collaborative, and mobile robots with the ability to move, to sense their environment, to perform a task, and to cooperate with humans or with one another to achieve their goal. Application domains include home robots, robots for facility management, robots in daycare or hospitals, as well as robots in flexible shopfloor manufacturing.
- **Physical Awareness**: The physical awareness family refers to use cases where sensing and positioning are used together with communication and network intelligence to enable for instance physical scene analysis, tracking, context awareness, trajectory prediction, navigational support, and collision avoidance. The network sensing can be enhanced by embedded sensors and derivative information delivered by network nodes and surrounding devices. Example scenarios refer to cars, automated guided vehicles (AGVs), and drones as well as pedestrians and bikes.
- **Digital Twins**: The digital twins family collects a set of use cases where digital equivalents of the real world are created and displayed for interaction, control, maintenance, as well as process and component management. Digital twins can be part of managing manufacturing plants, construction sites, city infrastructure, or communication networks with or without real-time needs. Also, specific use cases around distributing the software between operators and network locations are included.
- **Fully Connected World**: The fully connected world family unites use cases demonstrating the need for ubiquitous network access and service coverage across the Earth's population. The demand for ubiquitous access to mobile broadband services goes beyond high-quality voice and video communication and applies to network function availability for crisis management, digital health services, or support of autonomous supply chains. Ubiquitous access will be enabled both through terrestrial networks (TN) and non-terrestrial networks (NTN) and amended by infrastructure-less network extensions to wide-area network deployments.
- **Trusted Environments**: The trusted environments family encompasses use cases of local environments, such as hospitals, schools, or homes for the elderly, which can deliver human-centric services and establish quality of life including health, well-being, safety, inclusion, and autonomy in daily life. These services are based on sensing technology as well as on AI/ML and compute support to create spatial and situation awareness and to enable context-driven intervention. Trusted environments are embedded in the wide-area network and guarantee strict protection of private data.

3.5 Immersive Experience Use Case Family

3.5.1 Seamless Immersive Reality (Representative Use Case)

3.5.1.1 Use Case Description

Today's technology and devices are precedents to the use case Seamless Immersive Reality which is expected to leverage existing and evolving XR technologies such as AR, VR, and MR. AR is characterized as perceiving the real world with an overlay of digital elements. VR establishes a fully virtual digital environment. Finally, MR refers to the real-time interaction of co-located or remote participants with representations of real or virtual objects blended into the real or a virtual world.

Immersive reality combines immersive telepresence and immersive collaboration. Immersive telepresence will allow remote participants to appear as physically present in the very same environment as co-located participants and perceive it as realistic thanks to stimulation of their visual, hearing, and haptic senses. Immersive collaboration will provide a fundamentally new way of interacting with people and on objects or topics independently of their location, their physical nature, or their abstract character.

Finally, seamless immersive reality targets at low E2E latency and service continuity between different modes like for instance between AR and VR or between MR and actual reality. Seamless immersive reality will achieve a quantum leap in quality of experience (QoE) facilitating interaction, collaboration, co-presence, and co-experience in many if not all aspects of life including work, be it in the office or on a construction site, in education, or healthcare, as well as in many aspects of our cultural, social, and personal lives.

One can think of numerous work-related scenarios. For instance, a team of architects may collaborate on a volumetric model of a projected concert hall, listening to spatial audio renders consistent with their assumed position in the auditorium, experimenting with floor plan modifications, or changing the interior design. Sponsors may be walked through the projected concert hall to explore the atmosphere and acoustic quality, or to see alternative concepts and understand the architects' design decisions. A multi-site enterprise may target at fuelling synergies, productivity, and innovation in cross-site immersive collaboration meetings. Immersive reality teleconsultation will allow doctors to obtain anamneses of remote patients more efficiently and to provide better and more comprehensive diagnoses. Finally, instructors, teachers, and lecturers in an immersive reality environment will be able to offer more lively interactions with and between distant students.

Seamless immersive reality scenarios are equally beneficial to our private lives. Social activities and entertainment can be enjoyed together with distant friends which otherwise would only be possible when taking long trips. In relaxing moments, distant family members can be virtually visited in an immersive telepresence session. Thanks to immersive reality, a better understanding of our relatives' situation may be obtained as their body language, facial expressions, gestures, intonation, mood, location, and surrounding sounds can be perceived.

Problem(s) to be Solved/Challenges

- **Enabling significantly improved QoE**. Seamless immersive reality allows the end user to communicate and to interact – whenever there is the wish or the need to do so – with distant friends and family members as if they were physically present. As compared to a conventional video conference, an immersive reality session is expected to be more satisfactory and to provide a better mutual understanding among participants thanks to the 3D or even 6-degrees-of-freedom (6DoF) visual perception, spatial audio, and haptic experience. Likewise, end users can enjoy exploring cultures, participating in events, and socializing around the globe without the need to travel.
- **Living and working from anywhere**. For an employer, be it a company, an institution, or an administration, seamless immersive reality allows for new ways of working. Employees will be able to team up in an immersive collaboration session with colleagues, customers, and clients independently of location or of a person's disability and will benefit from a more natural interaction among people and with virtual or (a digital representation of) physical objects as compared to today's remote collaboration tools.
- **Achieve seamless service continuity**. Service continuity needs to be established by a meaningful and seamless service differentiation across local, hybrid, and fully immersive scenarios as well as across wide area and local wireless networks.
- **Ensure privacy protection.** Seamless immersive reality requires sharing location, personal, and sensor data. Technical and administrative/legislative means are required to protect privacy in a hierarchical and heterogeneous 6G system, i.e. across wide area networks, public and private local networks, as well as subnetworks.

Why 6G is needed

New 6G capabilities, i.e., sensing and AI/ML-related capabilities, as well as positioning, are key technology enablers for Seamless Immersive Reality. In addition, the high demand for privacy protection is expected to be improved by 6G.

The KPIs of the user-experienced data rate, area traffic capacity, and the positioning accuracy extend beyond 5G. Enabling (very) low E2E latency is expected to be improved by 6G.

3.5.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (cost)
Environmental	• Increase in resource efficiency in other sectors, such as transport and energy • Reduces the need for large physical spaces and extensive venue infrastructure	• Increased electronic waste from the disposal of devices and network equipment • Increased material consumption from producing the hardware components and expanding network infrastructure including raw material extraction, manufacturing processes, and transportation • Increased energy consumption and associated Greenhouse Gases (GHG) emissions to power devices, data centres, and active network component
Social	• Enhanced educational possibilities • Enhanced job opportunities • Enabler to participate in social environments (e.g., education, working environments, cultural events, socializing events, etc) • Enhanced quality of life and mental health with more opportunities for social interaction, and due to inclusion and well-being • Enhanced and interactive cultural and educational experiences	• Potential digital divide, digital inequalities depending on access, information technologies (IT) literacy and economic status • Privacy concerns of human digital footprint • Potential risks for trustworthiness in case of hacking • Potential risk for individual isolation and alienation (i.e., loss of human physical contact) • Potential risk for enhancing manipulation (proteus effect: representation of avatar may influence behaviour and attitude)
Economic	• More efficiency/ productivity • Reduced cost for knowledge transfer (efficiency, cost-efficient) • Increased quality with less cost through information exchange • Profitability – new use cases enabled • Economic benefits from the use of efficient virtual training environments	• Equipment cost affecting profitability • Costs from service and maintenance of the gear • Cost of learning as mitigation strategy, equipment needs to be designed for easy use • Massive initial investments

Table 3-2: Seamless Immersive Reality Sustainability Analysis

Environmental

Seamless Immersive Reality has the potential to optimize management and improve efficiency of resources in various sectors, such as energy, transport, and infrastructure planning. Depending on the application scenario, this use case leads to a reduction in physical travel for work or education and it consequently reduces the need for large physical spaces and extensive infrastructure.

Seamless Immersive Reality also comes with potential negative environmental impacts including an increase in resource consumption from the manufacturing of user and infrastructure equipment needed to support the various applications, and an increase in energy consumption required to power up additionally deployed infrastructure, devices, intensive computing, and data centres. The disposal of devices, including headsets, sensors, and associated peripherals may result in an increase in electronic waste. Additional environmental footprint from network densification, i.e., small cell sites, is expected as well as an increase of electronic waste from infrastructure parts' upgrade and exchange. Therefore, it is crucial to adopt mitigation strategies to minimise the negative environmental effects, such as the design of energy-efficient hardware and software, optimization of content and storage strategies, as well as circularity design and management practices.

Social

Seamless Immersive Reality enables people to have a realistic experience of the activities they are engaging in. These tools can be employed for work, e.g., meetings, as well as for educational or recreational purposes, (e.g., cultural immersion in social events).

However, Seamless Immersive Reality can carry potential risks of alienation and isolation due to the absence of human interaction in the real world for some individuals. Furthermore, the vast collection of data for proper operation may cause privacy concerns and trustworthiness issues, especially in the case of a security breach. Therefore, it is crucial to couple these experiences with a solid education on the balance of digital/real worlds, especially for children and teenagers. Finally, community support, the sharing economy, and policies can be employed as mechanisms for reducing inequalities caused by the inability to access these services.

Economic

Seamless Immersive Reality can improve economic efficiency and productivity of operations. There can be reduced costs for knowledge transfer from cost-efficient service delivery. Increased quality with less cost could be possible through information exchange. Profitability through enabling new use cases could be improved. There can be economic benefits from the use of efficient virtual training environments. On the cost side, equipment costs can degrade profitability. There will be costs from the service and maintenance of the gear. The creation of the seamless immersive reality environments requires massive initial investments. Finally, the creation of restricted or even exclusive clusters of professionals who can use the new immersive reality services can be a cost.

3.5.1.3 Example Service Scenarios

Immersive Collaboration Meeting, Immersive Classroom

Collaborating**,** discussing, and learning in an immersive setting with remote and co-located participants.

Participants interact with each other using tools natural in an immersive reality environment, and participants interact with virtual or digital representations of real objects, manually exploring, modifying, disaggregating, and re-assembling 3D models for instance of complex molecules in an immersive chemistry lecture. Due to the seemingly natural perception and interaction, the learning effect as well as inspiration, innovation, and productivity are enhanced. This service scenario also captures cases where there is the need to seamlessly switch from a hybrid to a completely virtual mode of collaboration without losing the content or the knowledge the participants had jointly built. The immersive classroom may be:

- **Local**: where all students are physically co-located and learn with virtual objects, or
- **Hybrid**: with both physically co-located as well as remote participants, or
- **Fully immersive**: where students and instructors are virtually present.

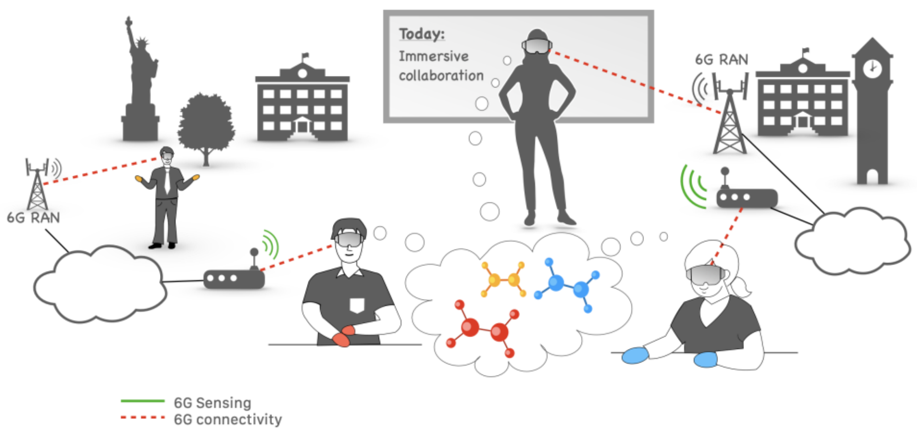

Figure 3-2: Hybrid Immersive Classroom Scenario

Figure 3-2 shows a hybrid immersive classroom scenario. The "orange-handed" student and the teacher represent participants remote to the physical classroom while the "red-handed" and the "blue-handed" students represent participants physically present in the classroom. The equipment local to the physical classroom senses the real environment, communicates the actions and the outcome of the collaborative molecule assembling, and communicates to establish immersive co-presence of the remote and physically present participants.

Immersive Experience "on the go"

Immersive experience while on the way to the office, on errands, or on a city exploration tour.

Immersive experience may refer to information obtained "on the go" such as information about sight-seeing landmarks, about the best way to reach a sports stadium, or a shopping centre, and it can be information about anything that can be searched for, or that can be looked at, pointed to, or touched.

Similarly, an "on the go" immersive telepresence session may be launched to invite a friend for a virtual city exploration tour or to connect with relatives in a more comprehensive way.

Immersive experience "on the go" may range from guidance information as augmentation overlay on the real surroundings to fully immersive reality with a sensory mix of vision, hearing, and haptics. The user of an "on the go" immersive experience may be:

- **Pedestrian or casual cyclist**: leading to high safety requirements and hence to limiting the degree of immersion as real-time interaction with the real environment is necessary, or
- **Passenger**: of a vehicle, a public transportation vehicle, or an enterprise shuttle bus, offering low latency and high throughput network access.
- **Stationary**: in the neighbourhood, in a city park, or in a restaurant.

3.5.1.4 Deployment Aspects

Environment & Type of Deployment	**Local wireless network, primarily indoor, private, and public networks:** private networks are expected in educational institutions, in enterprises, on industrial sites, or in company shuttle buses; public networks refer to coverage in train stations, public transportation systems, or shopping malls. Support of (very) low latency by peer-to-peer and mesh networking of co-located users and (very) low latency deployment in local wireless networks to reach a local AI/ML and compute server and to synchronize remote and local users. **Wide area network, outdoor and outdoor-to-indoor, primarily in urban and sub-urban environments:** serving city centres, office buildings, apartment buildings, museums, private homes, parks, sports stadiums, street environments. High density deployment of small cells with high bandwidth required. Network planning and deployment of mobile edge computing for very low latency support and high area traffic capacity.
Users and Devices	Main devices are those for use cases requiring **reliable high data rates with bounded latency** as introduced in Hexa-X-II D5.2 [HEX223-D52]. At least one device per user is connected to a local wireless access point or to the wide area network.

Constraints and Challenges	High cost of cellular small cell sites as well as for mmWave access point deployment in local networks. High area traffic capacity deployments may cause interference issues. Safety is a critical aspect when people move in crowded environments with traffic while interacting in digital worlds. UE constraints need to be considered for offloading, particularly for scenarios involving high data rates. Service continuity by service differentiation across local, hybrid, and fully immersive scenarios. User privacy protection in and between wide area, public and private local networks.

Table 3-3: Seamless Immersive Reality Deployment Aspects

3.5.1.5 Requirements and KPIs

Requirements

- **AI/ML and compute**, device-embedded and/or provided by the network: for creating a seamless immersive experience this use case may require AI/ML and compute capabilities to render 6DoF video and spatial audio, and to solve intelligence tasks for immersion and interaction like for instance object detection and tracking, or gesture recognition.
- **Sensing**: immersive experience requires the human sensory system to receive realistic stimuli from a mixed or virtual reality. Some scenarios may use joint communication and sensing (JCAS) or may apply sensor fusion of network and sensor data of connected sensors.
- **Positioning:** this use case requires accurate positioning for a seamless immersive experience. Network-based positioning may be needed for some immersive telepresence scenarios.
- **Privacy protection:** sensing technology and the need to share data for immersive telepresence create a high demand for privacy protection.
- **Service continuity:** service at a minimum level to provide a sufficient and for the end user comprehensible and satisfactory QoE across diverse locations ranging from local wireless networks to the wide area network.
- **On-body and in-body sub-networking capabilities:** for immersive experience including haptic actors and sensors on-body sub-networking capabilities, for in-body monitoring applications even in-body sub-networking capabilities, may need to be supported.
- **Synchronization between participants and data streams:** protocol stacks need to support low E2E latency in synchronization of participants and inter-participant data streams.
- **Digital immersive mapping as a service:** to assist seamless immersive reality, digital immersive mapping is provided as a service by the network.

KPIs

	KPI	Target Range	Justification
Communication	User-experienced data rate [Mb/s]	< 250	DL, also UL, for instance, if the UE takes the role of a gateway
	Area traffic capacity [$Mb/s/m^2$]	< 250 < 20	Indoor: per floor in a multi-story building Wide area: focus on immersive experience "on the go"
	Mobility	seamless HO	Pedestrian up-to vehicular speed for mobile passengers
	End-to-end latency [ms]	< 10 < 50 < 150	Split rendering Voice Collaboration
	Reliability [%]	99.9– 99.999	Depending on service and data stream
Positioning & New Capabilities	Positioning accuracy [cm]	≤ 10 horizontal ≤ 10 vertical	Some services may use network-assisted positioning; high positioning accuracy typically requires device-based sensors and sensor fusion.
	Sensing-related capabilities [Y/N]	Y	Some service scenarios may include JCAS or may apply sensor fusion of network and sensor data of connected devices
	AI/ML-related capabilities [Y/N]	Y	Device-embedded and/or provided by network

Table 3-4: Seamless Immersive Reality KPIs

3.5.2 Immersive Education

Ensuring accessibility and quality of education has been challenging due to a lack of infrastructure, logistic challenges, appropriate tools, and due to the digital divide. An example of such challenge is the COVID-19 pandemic that forced schools all over the world to physically shut down and operate in a remote fashion. Difficulties to establish meaningful student-teacher or student-student interactions, lack of suitable digital learning environments, and low-quality internet connections affected education scope and quality.

How much more students might have benefitted from a class on history, biology, mathematics, or any other subject if immersive experience solutions had been available for meaningful collaboration and immersion in a virtual classroom or a virtual lab. The pleasure of curiously exploring by virtually seeing, hearing, touching, and maybe modifying structures like an ancient building, a molecule, or a 3D model will raise motivation and attention to the content. Likewise, workers for instance on a construction site or an offshore oil platform face very specific safety risks for their own health and the health of their co-workers. Trainings to avoid or to master hazardous, safety-critical situations is costly, if these trainings happen in the actual environment, with actual equipment, and if instructors need to be physically present. A safe, cost-efficient, and environmentally sustainable method could be to train in an immersive virtual reality setting across multiple sites.

Targeting widely extended service coverage, the Immersive Education use case implies universally accessible high-quality wireless networks, extreme coverage including NTN, and local wireless networks as well as local networking based on sidelink and mesh networks embedded in the wide area network. Access to Immersive Education means to provide service continuity at a minimum level to provide a sufficient and for the end user comprehensible and satisfactory QoE across diverse locations ranging from local wireless networks to the wide area network and even to underserved areas connected by satellite.

3.5.3 Immersive Gaming

Immersive Gaming offers 3D immersive experience entertainment in gaming and e-sports to a single player and/or to multiple remote players in an indoor environment such as players' homes, gaming arenas, and schools. Real-time gaming services can be provided to multiple remote players within a network or among different networks. Using AR/VR/MR equipment and sensing a player's motion as well as objects in the room is a requirement for interacting with other players and the virtual world.

Accordingly, high user-experienced data rates with low E2E latency are required. Furthermore, service reliability and positioning accuracy need to be improved.

3.5.4 Live and Interactive Immersive Content Creation

Live and Interactive Immersive Content Creation offers consumers the possibility to enjoy immersive content tailored by content creators. Using network Application Programming Interfaces (APIs) to adapt the service delivery to the changing content allows for creating an engaging immersive experience that fully leverages the network's capabilities.

This use case builds on the seamless immersive reality use case with the following additional requirements: Live content contributors need to be able to transmit at very low latency to a system node ("mixing table") which combines the live content of multiple contributors to a single, well-orchestrated experience. For the best possible experience, content providers need to adapt the content to specific conditions of the consumers. Finally, network APIs are required to include experienced designers into the process of live content creation.

3.6 Collaborative Robots Use Case Family

3.6.1 Cooperating Mobile Robots (Representative Use Case)

3.6.1.1 Use Case Description

At the centre of this use case are autonomous robots with the ability to move, sense their environment, and perform a productive task. These robots can communicate with one another, with other machines, and with nearby humans to perform individual tasks that contribute to a common cooperative objective. The purpose of communication is safety and cooperation, to enable a group of robots to perform tasks beyond their individual capabilities and to enable individual robots to perceive their environment beyond their local capabilities.

This use case focuses primarily on local ad hoc connectivity embedded in private networks. Scenarios may include industrial manufacturing campus, construction site, and smart living.

In this context, the network of the future is envisioned to enable local cooperation among robots, to support autonomous task-solving by the robots, to enhance the safety of human-machine interaction, and to ensure that only authorized machines and humans can participate in task solving.

Problem(s) to be Solved/Challenges

- **Understanding and addressing the communication requirements of machines in the future.** This includes existing industrial automation systems, as well as the emerging type of *autonomous embodied agents* that encompasses industrial robots, service robots and cobots, i.e., collaborative, cooperating, or cognizant robots. These robots interact with the physical world through sensors and actuators, utilize advanced machine learning for decision-making, and employ wireless connectivity to collaboratively perform complex tasks and adapt to changing environments.
- **Using limited resources efficiently (materials, energy, and human effort).** For a sustainable development, it is essential to further automate well-defined, structured, and repetitive tasks in the physical world. This will require advances in connectivity for smart tools and machines that will allow mobile robots to collaborate, thereby optimizing productivity, resource efficiency, and costs.

- **Adapting to dynamic requirements of the market.** In the future, the ability to address real-time fluctuations in demand and personalized customer specifications will be essential in industries such as manufacturing, transportation, construction, and logistics. A key advantage will be the ability to use machines in different configurations. Within a collaborative network, the potential of a single machine to leverage the capabilities of other machines amplifies the versatility of the fleet. Combined with enhanced automation, this allows for more agile responses to real-time market requirements.
- **End-user access to custom manufacturing.** Enhancing the capabilities of end-users, including tradespeople and individuals without technical expertise, to manufacture products such as mechanical components, electronic devices, and architectural structures, is a step towards self-sufficiency. As cooperating mobile robots make manufacturing processes more accessible and decentralized, goods can be produced as and when needed at the specific locations where they are needed. New possibilities for customization will emerge. This shift will transform business relationships, and lead to transparency and accountability in the manufacturing sector.
- **Safe and trustworthy interactions with tools that can make decisions.** As robots gain decision-making and collaboration capabilities, one major concern is the assurance of human safety and the establishment of trust when these autonomous machines operate in human-inhabited spaces.

Why 6G is needed

The exchange of locally relevant information between robots will be crucial for cooperation. Key building blocks are the evolution of embedded device-to-device communication towards subnetworks, and mechanisms for local reservation of communication resources. Mobile robots may need the capability to request and establish these reservations when local connectivity is required.

5G ultra-reliable low-latency communication does not meet the latency, reliability, and scalability requirements in demanding scenarios. Increasing the adoption of existing millimetre waves and the development of new sub-THz connectivity may play a key role in achieving latency targets and managing interference.

Cooperating robots significantly benefit from advances in machine learning. Network-side support for efficient exchange of training data, weights, and models, along with federated learning, will likely become relevant. Complementing the onboard computation capabilities of robots, offloading computation to nearby edge nodes may add another layer of efficiency. Moreover, future systems are expected to exploit context information derived from sensing, the application, or a shared knowledge base, to improve both application and communication performance.

The integration of sensing and positioning capabilities in the radio interface may aid with the collection of data that is needed for advanced machine learning applications. Trust management is crucial for safe machine-machine and human-machine interactions, and will require reliable, deterministic, and low-latency E2E message transport mechanisms along with secure sensing results, and manipulation-protected positioning.

3.6.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (costs)
Environmental	• Resource efficiency: Functionalities may be provided by machines with less materials, energy, and waste generated • Function integration eliminates the need for multiple dedicated machines with individual functions	• Energy is consumed and materials are used to manufacture, deploy, and operate robots and associated services • The manufacturing, including material extraction and industrial processes, and transportation of robots generate GHG emissions • The disposal of machines and devices results in increased electronic waste

Social	• Accessibility: help people perform tasks beyond human capabilities • Safer work environment. • Increased trustworthiness of on-time delivery of the expected outcomes • M2H support: Robots could fulfil assistance roles, such as supporting the elderly at home	• Rendering roles obsolete: may eliminate job roles involving manual, linear, and repetitive tasks • Robots and cobots may require human operators to obtain new skills w.r.t. their method of use and maintenance (IT/robots literacy) • Benefits of robots and cobots might not be distributed evenly among society • People's privacy may be breached by unauthorized use of robots' and cobots' sensors
Economic	• Increased productivity and enhanced competitiveness • New business opportunities may emerge from technology leadership in autonomous robotics • New business opportunities for individuals: Cf. "Accessibility" in "Social benefits" • New job opportunities	• Extra R&D investments. • Initial investments to purchase, install, and set up autonomous machines may be a barrier for smaller businesses or those in developing countries. • Increased reliance on robots/cobots can pose a risk in case of failures or cyber-attacks • Monopolization risks • The use of autonomous machines can raise new regulatory and legal issues

Table 3-5: Cooperating Mobile Robots Sustainability Analysis

Environmental

The flexibility and increased efficiency delivered by the implementation of Cooperating Mobile Robots can have potential reductions in resource usage for equipment production, coupled with minimizing waste generation and the implementation of circularity practices within the manufacturing processes. Furthermore, industrial automation can offer more efficient use of resources and energy usage (exactly when and how much is necessary) by improving precision, material handling, task coordination, and flawless operations.

However, implementation requires the manufacturing and deployment of networked robots and cobots, and their operations require energy consumption from sensors, communication systems, processing units, data centres, and the associated charging and maintenance operations, all of which have an environmental impact. Therefore, mitigation strategies must include the use of sustainable and ethically sourced materials, energy-efficient hardware and software design, and added renewable energy sourcing considerations. For the end-of-life phase, e-waste management and circularity practices are essential.

Social

Cooperative Mobile Robots can have a significant impact by relieving human participation in risky and arduous situations (e.g., construction sites, closed-pit mines, heavy lifting) resulting in safer working environments. Moreover, transferring these tasks to cobots can enable people to fulfil roles that previously were not suitable for them (e.g., age, gender, height, disabilities). However, shifting the demand for physical to IT-related skills can create a new digital gap. Additionally, cobots will reduce the dependency on human labour, enhancing trustworthiness in terms of punctuality and expected outcomes, but reducing available jobs. As a result, training programs would need to be put in place, as well as mitigation strategies to relocate those who will lose their jobs.

Finally, the hyper-connectivity of the environment has the potential to create operational and privacy risks if the cyber-security measures are breached. Therefore, it is crucial to contemplate a resilient and safe digital ecosystem.

Economic

Autonomous machines like robots and cobots can significantly boost productivity and enhance competitiveness. By operating around the clock, and performing tasks faster and more accurately than humans, these machines enable goods to be produced more quickly and resource-effectively. This increase in efficiency can potentially enhance the economic output of a company or even a country. Furthermore, the technological leadership in autonomous robotics can lead to new business opportunities at both a corporate and individual level, including increased accessibility.

However, there are also significant challenges associated with the use of these machines. R&D investments are necessary to develop new technologies for autonomous robots and cobots, and the total cost of ownership, including initial purchase, installation, setup, maintenance, and repair, can be a barrier for smaller businesses or those in developing countries. As technology rapidly evolves, machinery can become obsolete quickly, requiring continual investment. The increased reliance on these machines can also pose a risk in case of technological failures or cyber-attacks. There's also a potential monopolization risk if only large companies can afford to invest in this technology, which could reduce market competition. Additionally, the use of autonomous machines can raise new regulatory and legal issues that need to be addressed.

Robots can carry out a variety of tasks efficiently, which can lead to improved cost efficiency and profitability. On the cost side, investment is needed in the robots. There can be economic impact from the reduction of jobs that are replaced by robots. Profitability might be dependent on the use case requirements.

3.6.1.3 Example Service Scenario

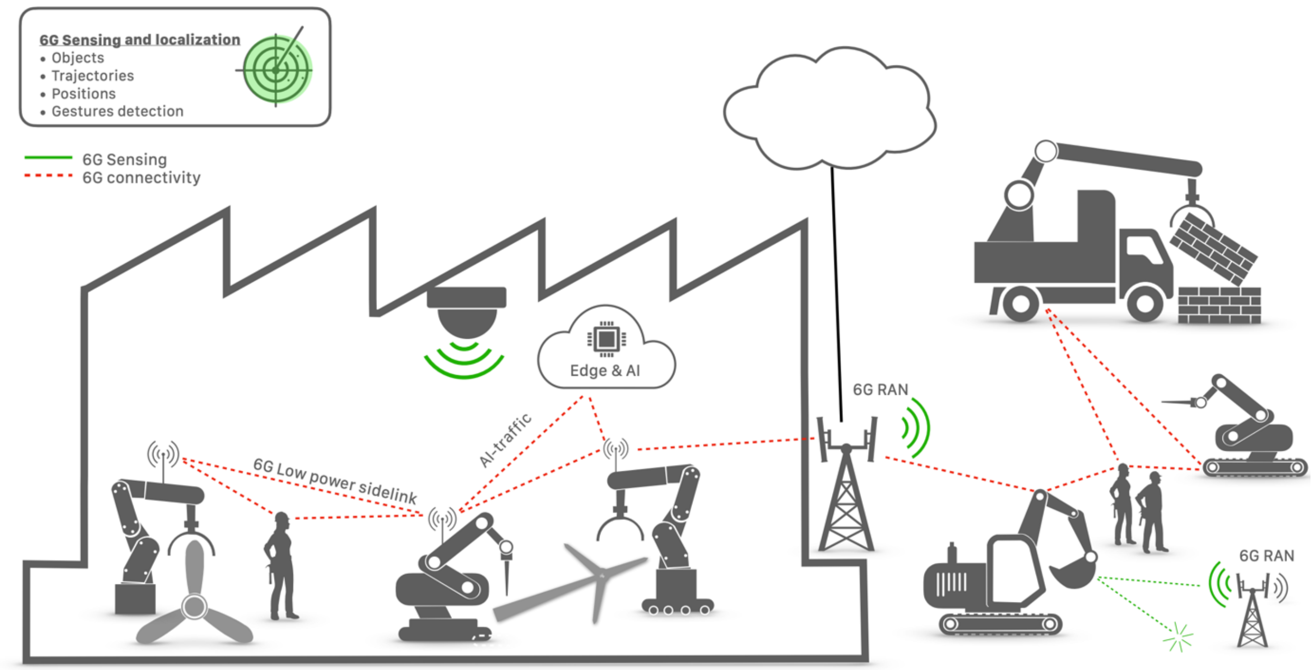

Figure 3-3: Cooperating Mobile Robots Example Scenario

Service scenarios within this use case family revolve around the need to complete a task that surpasses the capabilities of a single robot. The solution lies in robot cooperation, where multiple robots form a cluster to collaboratively accomplish the task. These robots utilize local ad hoc connectivity to establish a subnetwork for the following purposes:

- Coordinating and controlling their actions for successful task execution.
- Exchanging raw or processed sensor data.
- Sharing AI/ML models, weights, and federated learning.
- Ensuring safety for humans nearby in the event of an emergency.

A subnetwork is task-specific, spatially confined, and time-bounded. Its creation is initiated by a device, in this case, a robot. The subnetwork utilizes a portion of the communication resources from the private network within which it is embedded. Once the task is completed, the subnetwork is disbanded, and the communication resources are subsequently freed.

Example scenarios where this will be beneficial include:

- Cooperative carrying with robots is a concept where multiple robots work together to transport an object that exceeds the carrying capacity of a single robot.
- Lot size 1 production is a manufacturing approach in which each product is created individually and uniquely, rather than in batches. This method is facilitated by the collaboration of robots with different capabilities within a production cell, as well as the cooperation between logistics robots and production cells.
- In warehouses or logistic sites, cobots perform automated industrial tasks (e.g., quality check at production line, movement of goods between different workstations such as from storage to shipping, or from quality check to repair), system diagnostics and functionality allocation of the participating robots per se (e.g., for repairment or charging) without disrupting the warehouse process.
- Autonomous farming refers to the use of self-driving, smart machines that work collaboratively in agricultural operations.
- An autonomous construction site is a concept where different types of robots work in unison to construct a building. The transportation of materials, such as bricks, must seamlessly integrate with advanced construction machinery like 3D printers. Other robots are responsible for post-processing tasks, such as drilling holes autonomously.
- In a smart workshop, cooperating robots seamlessly connect material flow between various manufacturing stations. A high level of integration and autonomy of the machines enables tradespeople and hobbyists to produce items that were previously only possible in a factory setting.

3.6.1.4 Deployment Aspects

Environment & Type of Deployment	**Considered scenarios are mainly small indoor, large indoor, and small outdoor areas.** In these environments, line-of-sight links may be scarce for macro cells. Thus, femto- or pico-cells should be preferred for beam-based coverage. Propagation models used for network planning should include the appropriate multipath effects. **Focus on private networks.** It is assumed that the environment in which the network is deployed is dedicated to a specific purpose, e.g., manufacturing, construction, living, and trade-offs among coverage, data rate, latency, reliability etc. can be tailored according to specific application needs.
Users and Devices	**Majority of users are machines**, with a comparatively smaller number of human users. **Device class is differentiated based on the robots' level of autonomy**. Machines with low autonomy, requiring frequent exchange of coordination messages, could potentially expand the "Highly reliable low latency" device class. Conversely, machines with a high level of autonomy, reliant on sensor data exchange and AI/ML traffic, fall into the "Reliable high data rate with bounded latency" device class.
Constraints and Challenges	**Power is generally available.** But power efficiency is nonetheless required for battery-driven devices like mobile robots. **The management and orchestration (M&O) must fit a single operator, private network.** Resources must be properly allocated for providing the cooperating mobile robot service with a certain level of QoS. In particular, the resource allocation is executed at the radio access level, either on macro cell or femto- or pico-cells and at the operator network level. Depending on the network architecture, the resources available on different segments of the network (e.g. transport, edge, core) must be properly allocated.

Table 3-6: Cooperating Mobile Robots Deployment Aspects

3.6.1.5 Requirements and KPIs

Requirements

- **Local ad hoc connectivity:** A collaborative task is characterized by its localized nature. Direct communication between connected devices allows this to be exploited, leading to the formation of subnetworks. These subnetworks, envisioned to be task-specific, temporary, and localized, are embedded within broader campus networks. This structure aids in meeting stringent latency and reliability targets within each subnetwork.
- **Extremely reliable and low latency communications:** Interruptions in industrial manufacturing operations typically entail huge financial and material loss. Safety-critical applications are intended to protect human lives. As such, applications in this domain have among the strictest service-level reliability and E2E latency requirements. The service area may be highly localized to subnetworks and increased autonomy in machines may accommodate lower reliability and higher latency.
- **Mobility:** The localized and ad hoc nature of subnetworks in a 6G environment may induce frequent handovers as machines join and leave. These subnetworks, while logically embedded in a campus network, may exhibit nomadic behaviour within it, and the roaming of subnetworks between different campus networks may also occur.
- **Sensing, positioning, and AI/ML:** Integrated sensing capabilities within the 6G network and devices (JCAS/ISAC) can potentially enhance a robot's perception of its environment. The introduction of AI/ML traffic types and AI/ML execution in edge nodes can further enhance robot coordination. For maximum accuracy, it is likely that data from device-based sensors will be utilized in fusion with information from the network.

KPIs

	KPI	Target Range	Comments / Justification
Communication	User-experience data rate [Mb/s]	< 10	Data rate between robot and campus network. Can be significantly higher locally in a subnetwork where raw sensor data and/or AI/ML traffic is exchanged.
	Connection density [devices/m^2]	< 0.1	Mobile robots occupy an area of 1 m2, and it is assumed that they occupy at most 10% of the overall area to ensure fluent mobility. The world's largest industrial manufacturing campuses accommodate thousands of robots.
	Mobility [km/h]	< 20	Slow vehicular
	End-to-end latency [ms]	< 0.8	Industrial machines may exchange coordination messages up to 200 times per second and can be triplicated for redundancy. This results in a transfer interval of ca. 1.66 ms. E2E latency limit is set to at most half that interval to ensure enough margin for ARQ. [22.104]
	Service-level reliability [%]	99.999 – 99.99999	Application-side safety net mechanism like "survival time" and "grace period" are employed to compensate occasional packet losses and delays at the link level. Selected applications may have an even more strict reliability requirement up to 99.999999% [22.104].
	Coverage [%]	—	Localized nature of a joint task makes local ad hoc connectivity favourable.

Positioning & New Capabilities	Positioning accuracy [m]	< 0.1 (fine) < 1 (coarse)	Tasks such as environment mapping, robot navigation, and inventory management require fine positioning. Tasks like robot localization need coarse positioning.
	Sensing-related capabilities [Y/N]	Y	Robots and cobots depend on capturing the environmental context. Network-integrated sensing may complement or replace dedicated onboard sensors. Efficient transport of data/information from connected external sensors is likely needed.
	AI/ML-related capabilities [Y/N]	Y	Robots and cobots depend on advanced machine learning. Execution may be embedded in the device and/or offloaded at a local edge and/or provided by the network as an over-the-top service.

Table 3-7: Cooperating Mobile Robots KPIs

3.6.2 Autonomous Embodied Agents within Flexible Manufacturing

In future production scenarios, such as industrial grounds, smart cities and hospitals, intelligent machines will be used to complement and even replace human labour. Whereas traditional robots can be defined as movable machines that obey direct commands and have limited self-deciding abilities, these intelligent machines can be understood as an artificial intelligence agent that has been equipped with a physical, movable body. As a result, these machines are referred to as *autonomous embodied agents* rather than robots.

Rather than simply coordinating with each other to fulfill a collective task, autonomous embodied agents oversee more high-level tasks, whose execution requires interpretation and decision making. In that sense, autonomous embodied agents aim at replacing human workers at complex tasks. For example, these agents could be given the order of replacing all instances of part A with part B in the products being manufactured, check the production line for possible problems or inefficiencies, or reconfigure the operation of other machines.

As with humans, autonomous embodied agents are not only the recipients of direct commands, but they can also have the initiative to inform about the status of other components in the factory or even spontaneously raise alarms. For this, they maintain an updated context which is used to translate the combination of abstract orders and the status of their environment into specific actions. This context is the result of processing multiple information sources, such as their own sensors and the communication network itself. Namely, the 6G mobile network providing connectivity to these agents will implement joint communication and sensing capabilities so as to provide the agents with global perception, rather than being limited to local perception. The reason is that, on the one hand, the accuracy of local sensors may not be high enough to ensure safe and efficient operation. On the other hand, having access to only local information for each robot may lead to suboptimal decision making. In this context, JCAS is envisioned to help ensuring power and resource efficiency over what could be accomplished by using separate infrastructures for communication and sensing.

As opposed to unintelligent robots that are directly commanded by an operator or tightly coordinated with one another, low latency and highly reliable communication are not expected to be as critical in this use case. Instead, supporting native access to positioning and sensing information sources, as well as native support for AI training and operation (e.g., by means of federated learning, collective reinforcement training, AI-as-a-Service, etc.) is the most crucial feature that the network must support.

3.7 Physical Awareness Use Case Family

3.7.1 Network-Assisted Mobility (Representative Use Case)

3.7.1.1 Use Case Description

In this use case, illustrated in Figure 3-4, vehicles (cars, AGVs, drones, etc.) are relying on the network nodes and devices for localization of connected and unconnected objects and for determination of their properties such as size and velocity, contextual info, trajectories etc. Vehicles have a reliable connection to the network, with services available in a well-defined service area. Networks measure the physical environment in traffic scenarios and analyse to detect objects, and aggregate data of device positions and from this large data set extract information to relay to vehicles. Position data shared with vehicles can include vulnerable road users (VRUs), such as pedestrians and cyclists.

This can be done on several levels; networks can provide raw or processed environment and position data, or navigational support ranging from collecting and sharing of data, over navigation assistance, to full operation, leveraging on beyond-communication capabilities. The network can thereby support vehicles with different levels of autonomy and different modes of operation and enable smart transport in urban areas.

Furthermore, there is a possibility to use the physical environment understanding around nodes and devices to improve communication to vehicles by tailoring beams, avoid blockers, etc.

Some examples of the services provided by networks are: *network assistance info* (warnings, trajectories, object locations), *network assistance map* (digital 3D map data), *network navigation* (route recommendations), *full operation* (remote control of vehicles) and **context-***aware communication* (beam forming, path selection, scheduling).

Problem(s) to be solved/challenges

- **Risk of accidents with intense and automated transport scenarios**. The use case enables connected vehicles to avoid collisions and see around corners. Network support is a secure, standardized, and reliable solution for vehicles.
- **Energy consumption and generated emissions from transport**. Urban transport can be optimized from an energy perspective and lean, unmanned, electrical transport can be supported through appropriate guidance. Network support also allows the reduction of weight of vehicles since fewer onboard sensors are needed, thereby reducing their energy consumption.
- **Cost of transportation of goods and people**. The use case supports increasing degrees of autonomous operation of transport, reducing operational costs. Network support also allows simplification of vehicles, reducing their cost.
- **Access to reliable transport**. Network support for autonomous transport improves the availability of timely, reliable transport solutions throughout society, e.g., delivery of medicines, emergency response, and food.
- **Privacy in public spaces**. Compared to video-based perception from vehicles, network perception has properties that can ensure a preserved privacy.

Why 6G is needed

To some extent, it is expected that a similar service could be delivered in a 5G advanced system, using eMBB service and positioning. Sensing may be supported in Release-19 but not likely in any live deployments until 6G. Total bandwidth can be higher in 6G and signals can be designed more freely.

Vehicle-to-anything (V2X) services are supported in 5G, but the support of wide-area critical communication services, considering 3D coverage, mobility, reliability, and resilience E2E, which can be combined into service availability, is not within the scope of 5G. 6G may add tools to ensure connectivity through multi-hop and multi-connectivity, and introduce new deployment models such as Distributed-MIMO.

The performance of network-based positioning in wide area scenarios is clearly not sufficient in 5G (<50m horizontal accuracy for 80% of devices and 30s E2E latency [38.855]).

3.7.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (costs)
Environmental	• Reduction of GHG emissions by improving the traffic flow at the intersections thus requiring fewer traffic lanes and freeing up space for pedestrians and green spaces next to the roads • Reduction in accidents would help reduce automotive waste generated by repairs and scrapping of unrepairable vehicles and the GHG generated in the process • Supported driving, including network-assisted small driverless electric vehicles, made more efficient will reduce fuels and thereby reduce related emissions	• Increased energy consumption linked to sensing activities, including data collection, processing, and communication within the network, sensing devices operations, as well as real-time requirements • To enable the positioning services, new low power devices would have an additional energy footprint for the compute needed at the core • Materials and energy needed as well as lifecycle emissions for additional Information and Communication Technologies (ICT) infrastructure
Social	• Enhanced safety and well-being through reduced transport-related accidents • Increased availability of transportation: automated/self-driving vehicles would decrease the need for human drivers' availability and could be available any time in any area • Preserved/uncompromised privacy (compared to video-based perception) • Enhanced continuity of transportation service even in rural areas (digital inclusion)	• Potential risks for privacy associated to localization data • Potential risks for trustworthiness in case of hacking (e.g., leading to more accidents) • Potential risks for wrong decisions made by AI/ML • Decreased job opportunities
Economic	• Reduced costs for stakeholders for improved profitability from using the network for the monitoring tasks instead of additional sensors • Improved efficiency by freeing resources for other use that can bring profits	• Safety/predictability risks with potential economic impact • Expenses of network infrastructure to meet the requirements for high reliability of services

Table 3-8: Network-Assisted Mobility Sustainability Analysis

Environmental

Incorporating more information related to the traffic systems can help deliver several benefits such as safer roads, lower traffic congestion, optimized driving, and reduced fuel consumption. Since the automotive ecosystem is huge and widespread, any efficiency gains achieved have the potential to have large impacts (e.g., network-assisted driverless electric vehicles have the potential to reduce GHG emissions).

However, the implementation of such solution requires the extension of network coverage, and manufacture, transport and installation of new equipment and devices, which would result in increased energy and material consumption, and potential electronic waste from discarded devices.

Social

Providing additional information to vehicles is key to creating safer environments, and reducing the risk of collision and accidents. Moreover, automated vehicles could potentially increase the availability of transportation means since they will not be constrained by the time that they can operate (comparing to e.g., humans' need for rest), the availability of professional drivers to conduct the route (especially in rural areas), etc. Additionally, replacing cameras with sensing capabilities from the network, can also help to decrease any privacy risks involved. However, some questions remain unanswered such as 'how to deliver a sensing system, when there are people who don't want to be sensed'. Also, how to ensure the system is resilient to any cyber-attacks, as well as resolving accountability issues for AI/ML decisions. Therefore, providing trustworthy networks is essential.

Economic

There can be reduced costs for stakeholders leading to improved profitability from using the network for the monitoring instead of separate systems. There can also be improved efficiency by freeing resources for other use that can bring profits. On the cost side, there can be safety and predictability-related risks. Building network infrastructure to meet the requirements for high reliability of services can be costly.

3.7.1.3 Example Service Scenarios

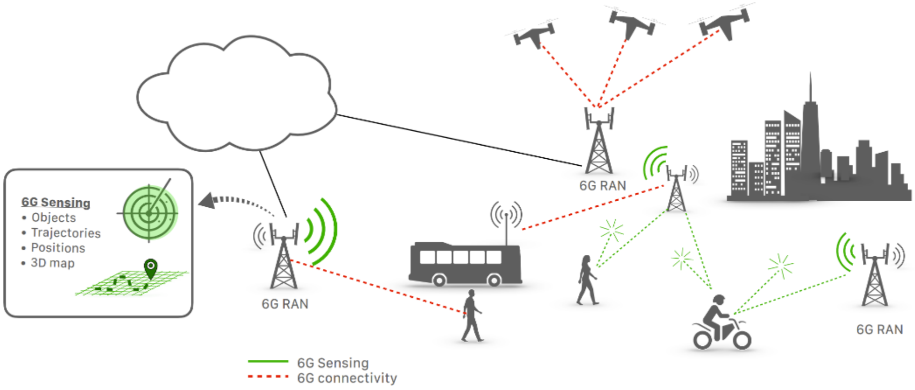

Figure 3-4: Network-Assisted Mobility Example Scenario

Autonomous Drone Transport

In autonomous drone transport, flying drones are carrying goods in urban areas. The drones are equipped with some sensors (camera, GPS, etc.) and a processor. Through the onboard 6G device they get a reliable communication link and can be positioned by the network. Over the communication channel the drone can receive timely information about nearby flight paths and activities and get recommended actions for fastest and most energy efficient path. It can receive a corrected position as well as map data from the network. It can also, depending on need, offload tasks such as image processing from the camera feed and share the resulting data on environment with the network. The users and deliverers of the drone transport service can count on a reliable, efficient, just-in-time delivery that can be tracked at any time, and people in the streets can trust that no collisions will occur caused by the drones passing over their heads.

Smart Intersections

Mobile communication infrastructure featuring sensing capabilities would enable a wide-coverage and well-connected radar mesh. Such network can be seen as a set of wide area sensors, that will add value to the users at almost no extra cost. Safety and efficiency of urban traffic can be improved by means of real-time spatial and temporal sensing of critical roads and intersections to support the vehicle when its sensors do not have line of sight. For example, even before a vehicle gets to a T-junction, it will be made aware of the conditions around the junction (such vulnerable pedestrians or other vehicles coming around the corner) so that the vehicle can take the right precautions to advert collision. Different from monitoring with video cameras, such sensing approach would allow perception even in complete darkness, or in adverse weather conditions like rain or fog (with certain performance limitations). Also, privacy concerns for citizens would be reduced as no actual video or picture would be used. Finally, sharing the sensed real-time data with traffic control centres can help to improve traffic flow management in smart cities.

Assisted Vehicles

Vehicles today have many onboard sensors to support applications such as cruise control, pedestrian detection etc. In the 6G era, the enabling of advanced automotive features such as autonomous driving and autonomous coordinated manoeuvring is envisioned through leveraging the wide area sensors from the network, in addition to on-board vehicle sensors. Autonomous driving would allow vehicles to be navigated through challenging traffic situations and terrains with no human interaction.

In addition, autonomous coordinated manoeuvring feature would allow multiple vehicles to autonomously navigate through roads and highways in a coordinated fashion to ease traffic congestion and improve the traffic flow. These advanced automotive features would require a comprehensive detailed knowledge of the environment surrounding the vehicles as well as high precision localization and positioning. This would be enabled by the fusion of the wide-area sensor information provided by the network, vehicle on-board sensors and/or even sensors embedded in the transport infrastructure.

3.7.1.4 Deployment Aspects

Environment & Type of Deployment	Transport services relying on network perception should be available outdoors in wide-area scenarios, primarily in urban areas but also in suburban and rural areas with more limited functionality. Many blockers in the form of buildings, vehicles, and fixed objects are expected in the main scenario.
User Devices	Several types of devices may be involved: • UEs will be mounted in moving vehicles that move along streets (on or above). These should be capable of high reliability, high availability, and low latency communication, as well as positioning capabilities. • UEs belonging to pedestrians and bikers etc. may also be temporarily stationary or slowly moving along streets. These can be expected to be standard smartphones. • Finally, UE roadside units may be mounted along streets to assist in measurements, e.g., bi-static sensing and positioning, and should have capabilities for this.
Constraints and Challenges	Likely need to deploy for Line-of-Sight (LoS) coverage in all of service area, if not non-LoS methods can be used for positioning and sensing

Table 3-9: Network-Assisted Mobility Deployment Aspects

3.7.1.5 Requirements and KPIs

Requirements

- **Privacy**: personal identities in public spaces must be handled in such a way that privacy is not jeopardized.
- **Localization**: Network nodes need to be able to perform radar-like measurements using the radio interface, to detect unconnected objects, which is delivered by JCAS functionality. In conjunction with this capability, precise device positioning is required. For both these capabilities, it is expected that networks will only be able to deliver part of the required precision and coverage. A sensor fusion functionality would therefore be needed, where networks collect data from multiple sources, e.g. onboard camera and GPS, and fuse it with the network measurements to create an enhanced dataset that is shared with the device and other devices.
    - High wide-area coverage for positioning and sensing services, also in 3D.
    - High detection probability of unconnected objects.

- **Connectivity**: Reliable communication is a critical aspect of this use case. For safety reasons, the link to the network should not be allowed to go down other than during very short periods within the service area. This may be difficult to achieve in practice considering 3D mobility within a city where links may be blocked at times. But the network should have the capability to predict and notify the connected vehicles such that they can take preventive action (e.g. stop or switch to a local operation mode). The network should also be able to timely activate adjacent links to ensure connectivity, e.g. to other devices and networks.
    - High resilience, availability, and reliability for connectivity in 3D; preferably without requiring excessive deployment of network nodes.
- **Compute**: Offload from the vehicles to the network of heavy processing tasks and training of models should be supported, as well as in-network real-time processing of sensor data. This means that the networks should have the capability of reliable compute and AI/ML-related functionality that can be accessed at all times from any point in the network.
    - Availability of reliable compute capabilities offered by the network.

KPIs

	KPI	Target Range	Comments / Justification
Communication	Peak Data Rate [Gb/s]	–	Not expected to be a challenge
	User-Experienced Data Rate [Mb/s]	1-10 (<100)	Depends on service type: lower for warnings and assistance, higher for digital maps. (For sensor fusion exchange of data may be higher.)
	Spectrum Efficiency	–	Same as for communication services
	Area Traffic Capacity [Mb/s/m^2]	–	Not expected to be a challenge
	End-to-end latency [ms]	20	Similar to V2X services.
	Reliability [%]	99.99	Fraction of packets within latency bound E2E
	Coverage [%]	99.9	Fraction of defined service space (in 3D) within latency bound.
	Service availability [%]	99.99	Probability to get communication service (as defined with E2E latency) within service space when requested. (Can replace coverage and reliability)
	Connection density [devices/km^2]	10^4	Not expected to be a challenge
	Mobility [km/h]	Up to 300 seamless handover	Speed of vehicles (cars, drones, trains) in urban areas. Handover within latency bound
Positioning & New	Location accuracy [m]	1 (3D) precision with 99.9% reliability within 99.9% of service space (0.1)	Reliable positioning with high availability important for use case, but likely multiple sources (e.g. from onboard sensors) can be combined to achieve more precise positioning. (Sensor fusion).
	Sensing-related capabilities [Y/N]	Y	Object detection probability, Object location accuracy/resolution, Object velocity accuracy/resolution, Object size accuracy/resolution.
	AI/ML-related capabilities [Y/N]	Y	Probability of a response time of compute/AI capabilities within a latency limit.

Table 3-10: Network-Assisted Mobility KPIs

3.7.2 Network Physical Data Exposure

This use case is about exploiting the network as a source of information on the physical environment, unconnected and connected objects, exposed as a service to a range of applications.

By combining input from network-based sensing and positioning, 3D maps, and sensor fusion of connected sensors, the networks are in a good position to maintain a digital twin of a geographical area. This includes information on the landscape itself and buildings, as well as people, animals, machinery, and vehicles.

Services that can be offered by the network include:

- Generate statistics about vehicles and transportation systems
- Analysis of traffic situations
- Estimating the number of humans or animals in an area, and flow of people
- Locating humans, animals, machinery, and vehicles
- Maintaining a geographical 3D database (physical digital twin).

Compared to Network-Assisted mobility, this use case is on a longer time scale and does not require the same level of reliability and availability.

3.8 Digital Twins Use Case Family

3.8.1 Realtime Digital Twins (Representative Use Case)

3.8.1.1 Use Case Description

A digital twin is an accurate digital representation of any combination of processes, products, persons, and functionalities of real-world items such as for industry, smart cities, or construction. This contextual digital equivalent of the real world offers a unified access to users and/or agents and is used for interaction, control, prediction, test, maintenance, and management of processes and components. To do so, it needs network connectivity to ingest data from multiple sources, e.g., databases, sensors, tags, network data, data models, and optionally steer/control the respective systems via feedback loops. A digital twin is aggregated, generated, and visualized by running dedicated software, including specialized AI/ML algorithms. The real-time aspect, enabled by the low latency capability of the 6G network, allows to extend the digital twin also towards direct control of the actual physical processes.

This use case covers the following applications (non-exhaustive list)

- DT in a manufacturing plant
- DT for water management and improved traffic management (smart cities)
- DT aggregation of sub-DT to cover complex systems (e.g. full smart cities)
- DT for 6G network planning and operation itself
- DT in port operations.

Problem(s) to be Solved /Challenges

- **Increase production quality and efficiency** (also resulting in reduced waste and emissions) by eliminating travel time and physical presence. Slow, manual interventions are to be replaced by automatic actions.
- **Prevent situations where humans are put at risk** by being physically present in unsafe environments; avoid cumbersome/difficult working conditions for employees (e.g. 24/7 human labour in continuous operations); prevent situations where the environment can be endangered.
- **Guaranty the privacy & trustworthiness**. Digital Twins require to share all types of data. Technical and administrative means are required to protect privacy in a hierarchical and heterogeneous 6G system. Privacy is especially important for smart cities.

- **Accessibility of DT models** for other DT models and for software agents. Digital Twins will cover large, complex systems as full cities, or complete factories. As DTs will first appear on lower level (machine level, one production line, one specific utility in a city), there will be overarching DTs popping up to cover the full system with the requirement to ingest, incorporate a number of underlying DTs (hierarchy/interop). This is also called "set of twins" or "massive twinning" requiring interoperability between DTs (also hosted over multiple clouds).

Why 6G is needed

Digital twins are already becoming available with the 5G network introduction, though more for isolated systems. For the deployment of overarching E2E Digital Twins (full production plants, complete cities, E2E networks, etc.) and for the real-time aspect, the introduction of a 6G network will be essential.

Only 6G can offer the required reliability (crucial for introduction in production) and the low latency of the connectivity (essential to introduce the real-time aspect) for commercial Realtime (RT) DTs. Furthermore, the 6G introduced network sensing and positioning accuracy enable an enhancement of the existing DT models.

Next to the technical capabilities, 6G will also enable secure, low-cost and energy efficient connectivity and contribute to the sustainability, both in a direct and an indirect way, the latter by opening up new advanced use cases.

3.8.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	**Sustainability Footprints (costs)**
Environmental	• Reduced usage of natural resources (e.g., water management, smart cities) by improved monitoring • Reduced waste from the increase in the production quality and efficiency • Sustainable urban development • Reduced GHG emissions from avoided visits to monitored areas, and avoiding operations visits for network planning and operation	• Resource intensive IoT and material required to produce sensors and IoT devices • Electronic waste resulting from the deployment of sensors and equipment • Energy consumption required for processing real-time data, DT generation, data centres, IoT devices, and computing resources
Social	• Reduced dependency on humans (e.g., 24/7 monitoring), leading to increased well-being for humans • Enhanced inclusion/opportunities for particular roles, irrespective of age, gender, disabilities, etc • Increased trustworthiness on data /information availability due to real-time monitoring/control • Enhanced accessibility to drinking water and food and its management from DT related to water/food supply, agriculture, etc	• Potential risks to privacy in the event of a cyber-attack • Potential impact on employability and labour market. Must be studied further

Economic	• Economic efficiency improvements from optimizing operations via digital twins • Improved resilience and flexibility • Improved safety from using digital twin for virtual safety checks • Improved profitability from avoiding costs from problems by using digital twin for optimizing operations (avoiding delays and saving costs including testing before production with end users/customers)	• Possible increased costs from complexity of multi-stakeholder ecosystem • Increased costs from energy, digital twin model, equipment, training, maintenance • Safety/predictability of operations – increased business risk from using technology instead of human perception

Table 3-11: Realtime Digital Twins Sustainability Analysis

Environmental

The real-time aspect and comprehensive control offered by DTs can minimize the need for physical inspections and on-site maintenance, thus saving energy and reducing GHG emissions. Also, the optimization of industrial and manufacturing processes can lead to better resource efficiency, resulting in lower raw materials extraction and water usage. In applications like 'Smart Cities', DTs are key in implementing water management practices, leading to monitoring and managing natural resources more effectively, and simultaneously supporting urban development.

However, despite enabling higher process efficiency, the construction of digital twins can be an accelerator for IoT devices and other equipment, some not even existing today, and require manufacturing, deployment, computing power, network extensions, and so on. This results in increased material extraction and consumption of resources including water and land. Furthermore, increased material efficiency is likely to reduce costs and consequently create a rebound effect, which will further push for resource depletion. Therefore, it is crucial to incorporate sustainable design practices and monitor the lifecycle of each element. This includes, but is not limited to, the usage of eco-friendly materials, renewable energy sources, implementation of energy-efficient data processing solutions, optimized data centres, and edge computing, to name a few. Finally, other consequences will be further analysed in the next deliverable D1.3.

Social

Realtime Digital Twins allow for remote monitoring and control of systems. This reduces the need for 24/7 on-site monitoring and consequently improving the quality of life of the workers subject to those shifts. It also helps to bridge the gap related to distinct characteristics of the individual on their ability to do the job (age, gender, disabilities). Also, having a digital representation of an asset can help to predict and reduce the risks in the event of any issue (e.g., plant failure), which can affect the lives of the workers.

Depending on the domain in that a DT is applied, further social benefits can be envisioned. For example, applying DTs to water management systems or food supply chains (from farm to fork) can enhance the availability, accessibility, and safety of water and food for all.

However, the constant evolution of digital services creates a new gap related to IT literacy, as well as the replacement of given jobs by digital processes. It is crucial to consider these topics. Some further risks are related to sensitive data and cyber security. These risks need to be analysed and assessed either through legal and/or standardization arrangements or through incentives for the companies to train their workers on their new job roles.

Economic

Digital twinning allows many stakeholders to meet in a virtual place to improve the efficiency of operations. This drives economic efficiency improvements can drive improved resiliency and flexibility. Safety can be improved by virtual safety checks. Profitability of operations can improve by avoiding costs from problems by using digital twin for optimizing operations. On the other hand, costs arise from the complexity of the multi-stakeholder ecosystem. There are increased costs from energy, the investment and maintenance of the digital twin. There can be increased risk in safety/predictability from using technology instead of human perception.

3.8.1.3 Example Service Scenario

As an example service scenario for the Realtime Digital Twin use case, a production plant is used (e.g., Chemical but could be any manufacturing or production plant).

Typically, these plants are spread over a large area (ballpark one or more km^2), mostly outdoor areas but also including indoor facilities. The constructions will be complex and built in all three dimensions with potential metal obstructions preventing a line-of-sight coverage. Still, full 3D network coverage is mandatory over the full Digital Twin area. Besides the Digital Twin traffic itself, also the day-to-day traffic needs to be handled by the same network.

The network brings the connectivity, sensing and computing power while enabling reliable connections in an energy efficient manner and guaranteeing the required low latency (down to the ms level) to control the chemical processes in real-time.

Connected Sensors will extend the 6G network sensing capabilities where necessary, to offer the extra required data from every step in the production process. As the digital twin also needs to include all moving items on premise, also the tracking of movements and locations (via network sensing and optional external sensors) is required. This dense grid of sensors will need to be connected to the Digital Twin, potentially incorporating legacy connection technologies to allow reuse of already deployed sensors/systems.

The machines, robots and vehicles will be modelled for accurate planning for 24/7 usage and maintenance needs. Next to this, the RT Digital Twin can also be used for testing purposes, to simulate a specific configuration or setting before really applying it, in this way facilitating any decision or to consolidate and prevent dangerous situations and/or environmental challenges and come to a continuously adapting control of the installation.

To meet these challenges, the DT requires a virtual model of the full petrochemical plant, a complex physical entity, with the necessary AI /ML capabilities, the associated visualization capabilities for seamless user interaction and supporting multiple end-user devices (not only fully equipped goggles but also low-cost devices).

Finally, the M&O capabilities will need to evolve to cope with the more stringent requirements of a Realtime Digital Twin service: low latency, a high number of connected devices, and systems that need to be managed, monitored, and with life cycle management.

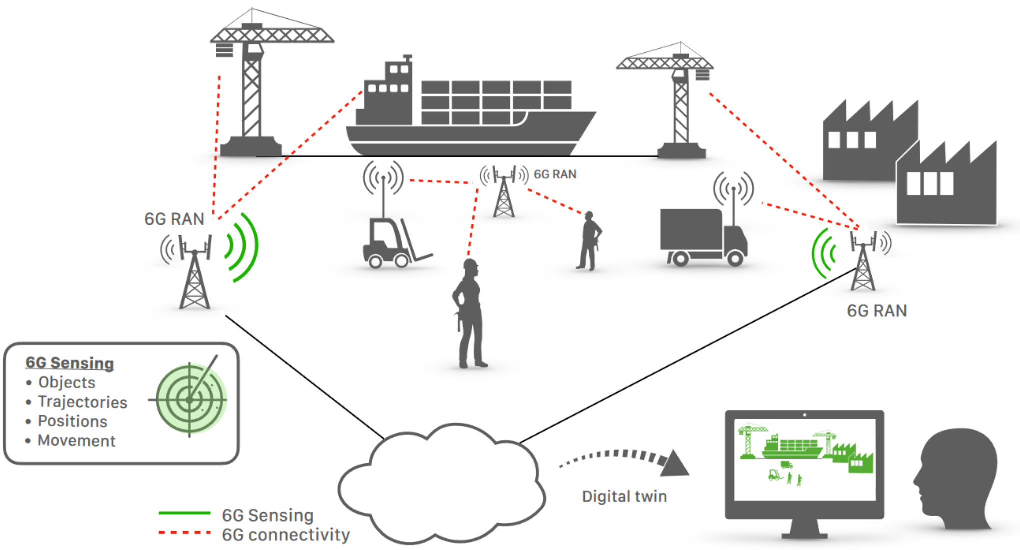

Figure 3-5: Realtime Digital Twins Example Scenario

3.8.1.4 Deployment Aspects

Environment & Type of Deployments	Following major deployment aspects must be considered for this use case: • Coverage from small to very large indoor/outdoor areas: The availability of macro cell coverage will not always be a given, so also network coverage via small cell and femto-cell (dedicated small footprint radio's with a communication over IP to the core, allowing plug & play) is to be considered. • Both public and private networks: For smart cities, the coverage will be provided by public networks. In factories, these will be replaced/extended by private networks. • Multi-operator environment: Even in factories, there will be elements in the digital twin that will be under public coverage, hence a multi-operator network needs to be assumed. • Machine-type communication: The target of the RT Digital Twin use case is to have the human interaction with the digital replica but the main type of communication on the network will be the traffic from M2M (periodic burst transmissions). • Seamless handover between the multiple deployment options.
User Devices	User devices, wearables, machines, sensors and actuators (for the feedback loop). The use case should support all types of devices, with different characteristics, capabilities, and classes.
Constraints and Challenges	Prioritization of low latency, reliability, sensing, and position accuracy. The required M&O capabilities.

Table 3-12: Realtime Digital Twins Deployment Aspects

3.8.1.5 Requirements and KPIs

Requirements

- **Realtime aspect:** Accurate control of industrial processes and components requires implementing low latency, and high available control loops between the system and Digital Twin as it is crucial to have an accurate synchronization of the physical and virtual states of the system. The very low E2E latency is mandatory to achieve a Realtime DT.
- **Full coverage:** The full physical geography of the DT needs to have complete network coverage with the appropriate QoS levels, including both indoor and outdoor areas and the locations without line of sight. Any handover in the network needs to be seamless.
- **Network Sensing:** the DT model is based on real-time data collected from the physical world. All sensing data collected by the network itself, eliminates the need for external sensors and reduces the complexity of the DT ecosystem and logistics.
- **Sensors:** Connected sensors are required for all extra data that cannot be provided by the network sensing, to create an accurate replica of the complex realtime environment. These sensors might also need a technology evolution beyond the current sensor devices for sensitivity/accuracy.
- **Improved human-machine interaction**: For an effective DT, it is crucial for users to have a seamless immersive interaction with the DT. To achieve this, all the capabilities/features as defined by the "Immersive Experience" use case family (also including the high-resolution 3D rendering) are required. (These are not duplicated here).

- **Compute** resources to handle the complex DT models and databases with the integrated advanced AI skills to simulate, steer, and predict.
- **Privacy/trustworthiness** supported by a secure network. Especially for smart cities, it will be crucial for the end-users to guarantee the privacy of the collected data.
- **Hierarchy of Digital Twins:** DTs will be covering larger, more complex systems as full cities and/or factories. As DTs will first appear on lower level (machine level, one production line, one specific utility in a city), there will be overarching DTs popping up to cover the full systems with the requirement to ingest, incorporate a number of underlying DTs (hierarchy/interop). This is also called "set of twins" or "massive twinning".
- **M&O capabilities** for the RT DT service to cope with the flexible resource allocation, since compute can be spread over the network core, edge, and device. Also, the sensing/sensor data collection needs to be orchestrated: not all included devices in the DT will have sufficient sensor capabilities and compute resources on board and will need to delegate this to the network (sensing and edge resources) or to other, better equipped devices in the vicinity.
- **Interoperability:** The DT might include deployed proprietary and legacy systems. Using open interfaces can make the network more flexible and more manageable (also from an orchestration perspective).
- **Strong system integrators** for the complex implementation of the RT DT, due to low compatibility and multiple technologies (networks, sensors, domain-specific software, other digital twin systems).

KPIs

	KPI	Target Range	Comments / Justification
Communication	End-to-end latency [ms]	order of ms	Very low latency for the realtime aspect
	Reliability [%]	99.99999	Very high: The control of realtime industrial processes requires very high service reliability. Can be lower for non-realtime DT
	User experienced data rate [Mb/s]	< 100	Low. It is expected video will be most demanding (up to 100 Mb/s)
	Connection density [devices/m^2]	1-10	High to cope with the high-volume of sensors (with very dispersed data rate needs)
	Coverage [%]	99.99	Service coverage both outdoor & indoor
	Mobility [km/h]	< 100	
Positioning & New Capabilities	Location accuracy [cm]	≤ 10	High. Accurate positioning to enrich the DT model
	Sensing-related capabilities [Y/N]	Y	Network-sensing: accuracy, resolution, and range to enrich the digital twin model
	AI/ML-related capabilities [Y/N]	Y	AI services can be provided by the service itself (embedded AI) or exposed by the 6G network (AI/ML provided by the network) but no AI-Native required (6G network AI).

Table 3-13: Realtime Digital Twin KPIs

Note: As stated in Section 3.8.1.1, several other applications are rolled up in this use case which will pose only a partial set of these Realtime DT required KPIs (so not the full set).

3.8.2 Cloud Continuum

Current technologies and market trends are driving a steady increase in the number of services running in the cloud, which will be further expanded in the 6G era. Moreover, 6G is not just about a radio interface, but also about a cloud architecture that supports a wide range of intelligent components (ICs) such as AI applications, immersive media components, or digital twins. These ICs can be implemented anywhere inside the cloud continuum of edge and centralized clouds.

With digital twins (DT) becoming omnipresent, it is foreseeable that companies will deploy DTs of their assets for various purposes. An example is an airline having DTs of all their aircraft engines, which are updated in real-time and hosted by cloud provider A in Paris. For maintenance purposes while in Singapore, engineers can use AR devices (hosted by cloud provider B) to portray the engine and work on it. However, the AR device also needs to optimize the quality of experience, requiring performing further media rendering/stitching in the edge cloud. The latter depicts the importance to have both "intelligent components" of the AR and DT being able to interoperate, even when hosted by different providers, in different locations. Also for DT's interacting with the "intelligent components" of other 6G-related devices, hosted by different providers, interoperability is key, explaining why a cloud continuum in the 6G era is a must.

For these dispersed ICs to be supported and operate properly it is mandatory that the availability, functionality, and interoperability must be seamless throughout the entire cloud infrastructure, irrespective of the cloud provider. An IC in one cloud infrastructure needs to be able to discover, authorize, and authenticate ICs in another cloud for them to interoperate. Therefore, the requirement towards 6G is to standardize interoperability between ICs across cloud/edge providers. 6G will have to provide a federated cloud architecture that supports all these collaborations.

3.8.3 Smart Maintenance

The smart maintenance use case targets to minimize the downtime of the system covered. It is a top priority for operators, manufacturers, and service providers to avoid downtimes. Given the pervasive nature of IT systems in our daily lives, downtime can have severe consequences for society and economy. Therefore, the ability to predict and prevent outages is crucial in reducing downtime and mitigating its negative impact.

The smart maintenance relies on fault prediction, which involves collecting and storing all related data while using Al/ML and/or statistical algorithms to predict system behaviour, including failure events. Another key aspect is to trigger proactive interventions on systems, before their predicted faults occur, preventing system outages.

The storage and computational requirements may be very high, depending on the model and algorithms employed, as well as the number of devices and parameters monitored. This can be addressed by leveraging cloud computing resources located conveniently without latency-distance constraints from the devices. The other Realtime Digital Twin KPIs as latency and reliability are not that critical for this use case.

The smart maintenance use case can be deployed for multiple scenarios, including smart industries, smart homes, smart cities, as well as for the 6G network itself.

3.8.4 Digital Twins (Building Model)

The global construction industry is a massive one: expenditure surpassed $11 trillion in 2022, so approximately 13% of the global GDP. It promotes economic development and brings many non-monetary benefits to countries such as safe and clean housing for all. However, the construction industry also faces serious challenges related to low productivity, sustainability issues, conservative processes, and high levels of hazards and risks. Stakeholders are continuously focusing on improving all aspects of sustainability, including safety and efficiency.

Introducing a cloud-based digital twin, with its associated data, of a construction would enable all stakeholders and employees in a complex construction project (it can be considered as a temporary manufacturing plant) to have access to this digital twin via XR at any time, both outdoors and indoors and even in rural areas. Multiple simultaneous users can use it and enjoy a smooth, glitch-free, and accurate experience.

Complex project aspects can be fully experienced, understood, and adjusted in real-time using high-fidelity XR. Virtual safety inspections and guidance supported by AR overlays projected on smart helmet's visors help increase safety. Interactive collaboration is possible, including the use of shared digital objects and with immediate haptic feedback. Telepresence and shared virtual rooms allow experts to participate remotely. Network sensing and external sensors for continuous scanning of the project progress supported by AI for early detection of discrepancies and risks help to increase safety, efficiency, and environmental sustainability. Also in the property sales process, the digital twin will play a key role.

6G will bring the required ultra-fast, reliable, low-latency wireless access to the twins, also at remote sites, enabling seamless connectivity across organizations, exchange of vast amounts of accurate real-time data, remote collaboration and virtual high fidelity XR meetings and training for better safety and efficiency, vast arrays of sensors and devices, drones, robots/cobots, remote real-time monitoring of construction processes and environmental conditions, advanced AI supported data analytics and simulation of construction scenarios, network sensing and external sensors for real-time alerts to prevent physical collisions and for very accurate monitoring of a project's progress in real-time including even the smallest deviations from its twin.

3.9 Fully Connected World Use Case Family

3.9.1 Ubiquitous Network (Representative Use Case)

3.9.1.1 Use Case Description

The Ubiquitous Network use case focuses on delivering Mobile Broadband connectivity to every human on Earth, leaving no "white zones". It therefore involves providing network access everywhere, encompassing remote areas, zones with harsh geographical conditions (e.g., mountains, forests), the airspace for aerial operation (e.g., drone operation), as well as the open ocean.

This ubiquitous network will be enabled through seamless access to both TN and NTN – including satellites, High Altitude Platform Stations (HAPS), air-to-ground networks, and unmanned aerial vehicles/drones – in a transparent way for the end user, meeting the requirements (e.g., bit rates, latency) to ensure that every-day needs are covered, with the desired quality of service (QoS).

Although most users in these areas will not be able to enjoy the services with the utmost performance (e.g., no URLLC, or the most immersive experiences), they will be able to benefit from a wide set of services with reliable connectivity, including high-quality voice or video streaming services. Moreover, the configuration could also enable other 6G-related use cases, such as compute offloading if the technical/physical limitations allow it (e.g., no URLLC due to the use of satellites).

Ubiquitous Network will allow everyone on Earth to access the Internet and its most common uses, but it will also enable the delivery of new services, such as digital health services. Remote consultations with doctors will be possible in areas lacking medical infrastructure. Some institutions, such as schools, could also benefit from more advanced applications for remote virtual education.

Finally, integrating TN with NTN, allows the network to deliver guaranteed connectivity whatever the conditions, maintaining a minimum set of services even in the event of a crisis. This network resilience will be crucial for emergency services, in difficult climatic conditions such as storms (in which network elements may be damaged), or in natural disasters, such as floodings, earthquakes, tsunamis, human-induced catastrophes (e.g., conflicts) or other events that nowadays cause network downtime.

Problem(s) to be Solved/Challenges

- The main problem to be solved is **digital inclusion**, by giving everyone, anywhere the possibility to access digital services, bridging the gap between urban areas, with access to all services, and rural areas, with limited access, or even no access to digital services.

- Delivering ubiquitous connectivity can also help reduce educational gaps (by guaranteeing access to major educational institutions) as well as reducing gaps related to access to health services (by enabling remote consultation with a doctor), to name a few examples.
- Connectivity everywhere on Earth will not only be a benefit for humans. It will also be an enabler for earth monitoring, i.e., ensuring data collection from sensors, measuring everything from temperature to pH value, or even the DNA of animals in a geographical area to track biodiversity.
- Finally, expanding the ecosystem to include NTN delivers greater resilience to the overall network, which can be crucial in the event of disasters.

Why 6G is needed

6G is needed to ensure reliable **service anywhere for everyone**, meeting the QoS required for different uses, while providing privacy and security as well as allowing cost-efficient connectivity and device solutions.

Incorporating a tight integration of TN and NTN as part of the initial phases in 6G, allows for a cost-efficient ecosystem to be built, as well as ensuring service continuity. At the same time, 6G will address infrastructure-less environments which suffer from coverage gaps and network service in out-of-range areas that lack the flexibility to allocate enough resources in reasonable time (e.g., high-quality video service experience). 6G is needed to ensure seamless ubiquitous access in extreme environments even with low-cost solutions that can provide basic services, thanks to a **reliable integration of multiple networks**.

6G is also needed for trusted access, to encompass an approach of trustworthy-by-design infrastructure such that equipment from vendors of any origin can be trusted for private and secure communication.

In addition, 6G should bring **affordable cellular solutions from the start** to the ubiquitous network scenarios allowing worldwide deployment and adoption, even in low-income areas. The first 5G releases focus on chipset and terminal side has been on high-cost, and high-performance devices, whereas lower cost user equipment has been spun off as technology evolves, in the last releases, and it remains to be seen how well they will be adopted by the market and how efficient it will be for operators to support them efficiently without destroying overall network performance and experience. 6G needs to address these challenges in a better way already from the first phase.

3.9.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (costs)
Environmental	• Preventing travel-related emissions as a result of remote access to services • Enabling collection of environmental data for Earth monitoring • Access to precise status information can enable precision farming practices (agriculture, aquaculture) to reduce the use of fertilizers, pesticides, and fresh water	• Increased material and energy use to build this ecosystem (e.g., devices, base stations, satellites) • Increased land use (e.g., networks, data centres) could potentially impact existing habitat, and thus, biodiversity • Potential increase of e-waste on land, oceans and space if not handled properly (e.g., collection, 100% biodegradable)

Social	• Providing everyone access to the digital ecosystem • Providing access to digital services to all (e.g., entertainment, education, transactions, voting, etc.) → Bridging the digital divide • Contribute to making networks reliable (perception), everywhere • Enhanced trustworthiness of digital services (availability and accountability) • Delivering increased resilience in networks, crucial in unexpected events (e.g., natural disasters) • Enhanced healthcare and education to reach new areas • Increases food yield from enhanced agricultural management • New job opportunities	• Potential digital divide for people with functional variation/ageing population/IT literacy if all services are meant to be handled digitally • Potential risk to privacy if all services are meant to be handled digitally • Potential mental health problem due to possibility of always being connected and being traceable
Economic	• Improved economic resilience from wider availability of connectivity for different services • Efficiency improvements from the reuse of resources • Economic benefits (profitability) to society/country from combining ubiquitous network with other use cases (e.g. in public services)	• Profitability challenge from the network investment • Resilience challenges from the maintenance of network

Table 3-14: Ubiquitous Network Sustainability Analysis

Environmental

The access to internet for more people and devices provides increased possibilities for access to information and digital services in different industries, for example in agriculture/aquaculture, which in turn could lead to increased efficiency. From an environmental perspective, this could lead to reduced GHG emissions and reduced use of material. Having access to digital services may also lead to less travel. A ubiquitous network could also provide network access to Earth monitoring sensors, even in remote areas.

Enabling access for more users requires more devices, extended networks and more data centres, which requires more energy and material. It also requires increased use of land. With more equipment comes increased e-waste, both on Earth and in space, if not recycled or designed with 100% biodegradable materials. Especially important is to plan for how to handle the many sensors that will be connected to the network.

E-waste and circularity are also important aspects to consider for NTN since increased number of satellites will most likely result in increased space debris, such as non-functioning or broken satellites – or even satellites which were not completely burnt at their end-of-life. This will increase the risk of collisions, i.e., even more debris. Repairs in space, or the production and launch of replacement equipment, will of course lead to more material and energy use.

Social

Ubiquitous network delivers the possibility of connecting everyone, everywhere. Further to this, the aim is to offer network capabilities with not only universal coverage but also with capacity that can give to all access to more demanding services such as healthcare, education, cultural activities, entertainment, education, transactions, voting, etc., bridging the digital divide in terms of availability of these services to all. In stable and high-speed networks these services can be supported from DT and AR/VR technologies in order to offer remote and enhanced experience for all as well as trustworthiness in terms of reliability, availability and accountability. Remote access to such services through reliable and always available networks can offer new remote job opportunities as well as enhancement in the management of e.g., food and agricultural processes. Finally, ubiquitous networks are expected to offer increased resilience and thus, support people in natural disaster events.

On the other hand, increasing the digitalization of services always comes with the risks of a) creating a digital divide for people with e.g., functional variation, ageing population and IT literacy; b) privacy and c) mental health issues; if all services become available only digitally and people need to be always connected and traceable. All these risks can be limited or avoided with proper training from early ages in terms of balancing between the two worlds (physical vs. digital), recognizing digital world's hidden dangers (privacy-related or coming from anonymity), etc. The risk of digital division will need further investigation and study from domain experts. However, indicative mitigation strategies could include, e.g., a transitional phase where the services are supported both physically and digitally for all (or partially pending the characteristics of the end users); public support from authorized offices to support ageing populations or people with low IT literacy in fulfilling the interaction with the service they wish to use, etc.

Economic

There can be improved economic resilience from the wider availability of connectivity networks that can be used to deliver different services ubiquitously. There can be efficiency improvements from the reuse of resources. Economic benefits including improved profitability to society/country are possible by combining ubiquitous network with other use cases (e.g., in public services). On the cost side, there can be profitability challenges from the network investment. Additionally, there can be resilience challenges from the maintenance of the network.

3.9.1.3 Example Service Scenario

Connectivity at Remote Locations

An end user A, located in a mountainous area, with difficult access conditions, can now benefit from a wide range of services thanks to the seamless connectivity between terrestrial and non-terrestrial networks offered by 6G. Being far away from medical institutions and doctors, the user can consult doctors virtually, as the video quality allows the diagnosis of many common health problems (even though the bit rates and latency required are relaxed, video quality will be sufficiently good and improved with respect to 5G to allow finer analysis). If further analysis is required, the user will have to drive to the nearest hospital, but thanks to the improved video quality of the consultation, several round trips to the hospitals can be saved. In this example, there is therefore positive impact on both social and environmental sustainability.

It will also allow access to knowledge/education for people living in remote regions, or the possibility to be included as part of society (e.g., voting, payments), among many other benefits.

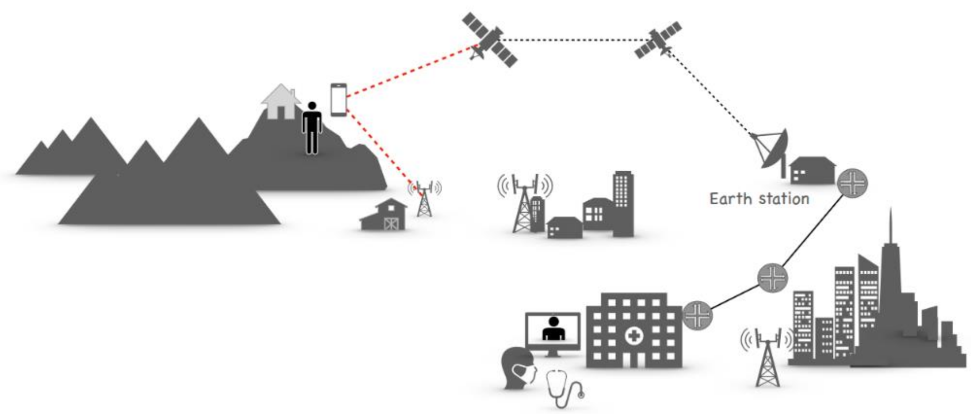

Figure 3-6: Ubiquitous Network: "Connectivity at Remote Locations"

Improved Connectivity in Developing Countries

An end user B, who is a small-scale farmer in deep rural Africa, with limited, if any, land connectivity when in the field, now has access to a wide range of professional services with one single device seamlessly connecting to terrestrial and non-terrestrial networks. Using a mobile application, the farmer can perform a diagnosis as close to the suspected anomaly (related to crop cultivation or livestock) as possible and has the option of adding photos and videos to help get to the root of the problem thanks to the remote support of agronomist expertise (human or AI). Farmers can thus engage with precision farming techniques (minimizing environmental pressures) as well as better addressing the pressure that climate change is exerting on their output (agricultural production).

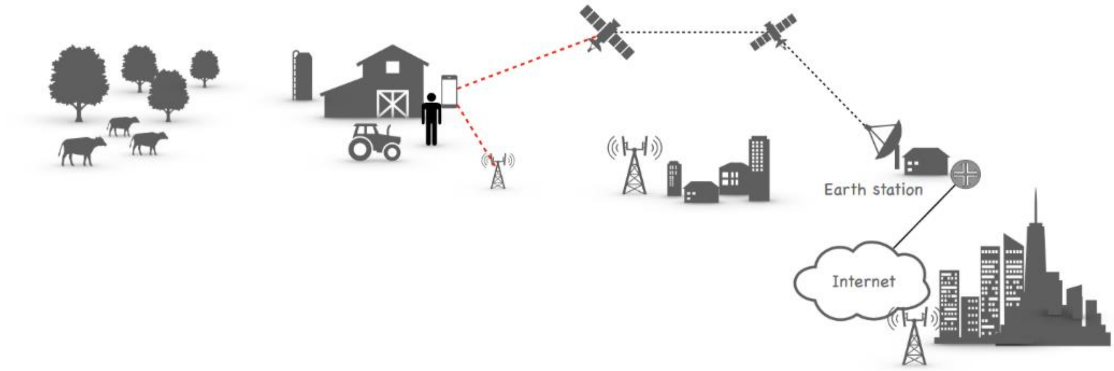

Figure 3-7: Ubiquitous Network: "Improved Connectivity in Developing Countries”

Connectivity during Natural Disasters and Emergencies

End-user C is working when an earthquake hits, damaging their office and trapping them under collapsed walls. Thanks to the resilient ubiquitous network, end-user C can inform end-user D, from the rescue team, and stream videos of their environment to help rescue teams localize them, characterize the situation and plan rescue operations. End-user C can also call end-user E, a family member, to inform them about their situation. A crisis scenario such as when an earthquake hits, can cause the connectivity to fail. This is due to the physical destruction of the infrastructure, or to the overload of the networks because of the reigning panic that pushes people to try to contact their loved ones. As many can be injured, the loss of connectivity can prevent those people from being treated in time, or providing ease to people knowing their relatives are safe. Since NTNs are less exposed to failures affecting the ground level, the complementarity of NTN and TN, through different access networks, will be necessary to act as backup for connectivity in these situations. This is an example of how, apart from connecting rural or extreme areas, NTNs can serve a great purpose in currently well-connected urban areas.

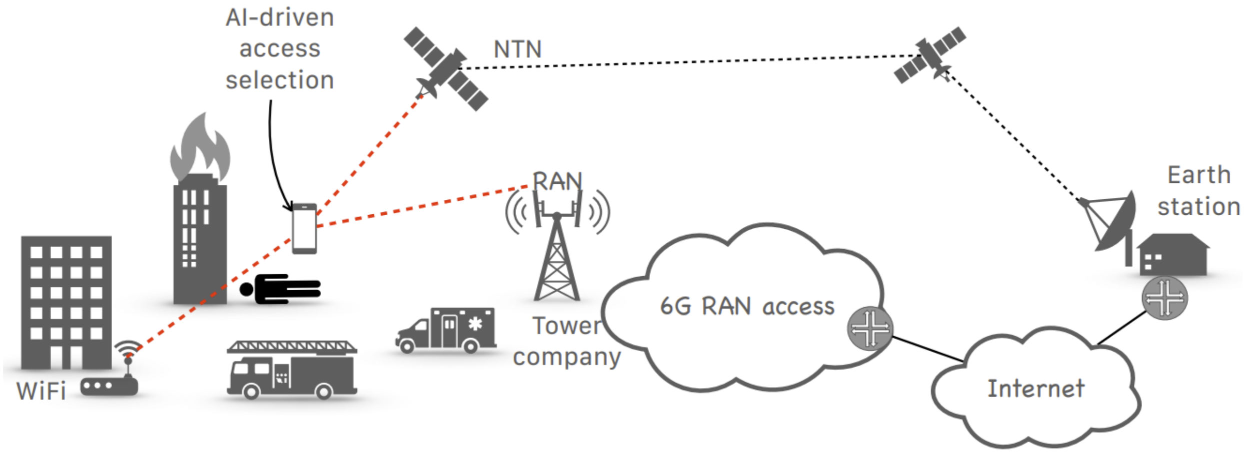

Figure 3-8: Ubiquitous Network: "Connectivity During Natural Disasters and Emergencies"

3.9.1.4 Deployment Aspects

Environment & Type of Deployments	**Outdoor coverage**: 6G should provide broader and deeper outdoor coverage as it is being built ubiquitously by integrating terrestrial, non-terrestrial and device-to-device communication; connecting sea, land, and air. **Indoor coverage**: Most of the mobile data traffic is and will continue to be generated indoors. Today, according to IDATE information based on data and interviews with European operators [IDA23], 75% to 80% of the data traffic, Business to Consumer (B2C) and Business to Business (B2B), is generated indoors and this is expected to grow in the next years. Many use cases rely on indoor coverage: healthcare, energy & utilities, industrial IoT, transportation & logistics, public sector, etc. Adequate investments to deploy the indoor network (vs. outdoor) remains challenging. Indoor coverage cannot be provided directly through satellite connectivity, but a Customer Premises Equipment antenna can be installed outdoor of the building and connectivity can be distributed indoor through another technology. **6G-NTN convergence for universal coverage**: 5G has already done some of the work converging with satellite; with satellite companies involved in 3GPP standardization, but 6G should go beyond. For various aspects (e.g., topography of the terrain, cost of deployment), it will not be possible to deploy TN everywhere, and deployment should build also on other type of networks, NTN. An example is an ambulance carrying a patient from a mobile white zone connected to satellite to urban areas for treatment. But the characteristics of the different NTN solutions should be accounted for in the deployment for specific services (e.g., latency requirements not compatible with service requirements).
User Devices	User devices: the Use Case should be able to address various types of user devices, with different characteristics (e.g., Mobile Broadband devices, Fixed Wireless Access terminals), and categories (e.g., costs). Earth monitoring can also rely on zero-energy sensors.
Constraints and Challenges	**Prioritization of service**: Also, in case of an emergency/crisis, the ecosystem should be able to operate in 'emergency mode'. This should reduce non-essential services to a minimum in order to allow a set of priority services to work properly. An example of such would be to reduce video streaming services to a minimum, to allow enough capacity for rescue services, calling, or other use cases that are aimed at the aid of people in such crises, and allow equal access to services to everyone.

Table 3-15: Ubiquitous Network Deployment Aspects

3.9.1.5 Requirements and KPIs

Requirements

The most important and challenging requirements for the technical design of 6G are listed below.

- **Connectivity**: The 6G system will need to provide ubiquitous access even in the most remote or hard-to-reach areas with extreme coverage needs. The range of the network will need to be extended to cover any "white zones" (outdoor and indoor) even in areas where it is not possible to deploy dedicated network infrastructure. Finally, it is not only required to provide connectivity in the surface, but also allow for 3D coverage targeted at commercial drone operations or deep underground areas where signal conditions are very poor.
- **Resilience**: The 6G system should be able to ensure resilient, seamless operation even in environments with intermittent or limited network connectivity. Services characteristics might vary through the coverage area, but basic services must be guaranteed.

- **Flexibility**: The 6G system must be able to deploy flexible network topologies (based on different accesses) to overcome obstacles such as limited infrastructure or signal attenuation/interference. End-user devices must be able to connect with different possibilities, e.g., allowing connection or offloading to a better proximity or more resource-efficient/capable device, or via multi-hop scenarios.
- **Service Continuity:** Tight integration between different topologies and network elements is needed, including the integration between terrestrial and non-terrestrial networks so service continuity can be assured for devices moving between different network topologies or deployments.
- **Privacy and Security:** Privacy and security requirements must be consistent and guaranteed, regardless of the access network (TN or NTN), and during handovers between each.
- **Affordability:** It is crucial to provide a cost-efficient E2E ecosystem (end-user devices, network infrastructure/operation) to ensure widespread adoption.
- **6G-NTN convergence**: In the vast part of the world, where fixed networks are not much deployed due to topography or high costs of deployment or low investment capability, mobile and NTN should push convergence where terrestrial-based and NTN-based solutions can complement each other, however having different service and cost characteristics. All necessary services should work properly, irrespective of the network in which the service is running on. Additionally, the convergence of these two networks requires that parameters, or other information, currently being used for a particular action will be provided by both TN and NTN. An example of such is the information related to "to which base station a handset is connected", which enables emergency alerts to be sent (e.g., sending tsunami threat alarms to all devices connected to base stations near the coastline in a given region).

KPIs

	KPI	Target Range	Comments / Justification
Communication	End-to-end latency [ms]	10-100	Depending on the service. It is targeting video calls/streaming. 'Real-time' interactions are not considered as part of this requirement (e.g., no remote surgeries).
	Reliability [%]	99.9 –99.999	The reliability KPI could be associated with the expected service (e.g., given NTN coverage, what is the probability of successfully fallback from TN to NTN and achieving a data rate of at least 100 kb/s). Success rate for this should be high.
	Availability [%]	98.5	Tightly connected to reliability (qualifying the success of transmission) is the availability of connectivity (qualifying the percentage of time the service can be delivered). Appropriate combination of full coverage and capacity to deliver video streaming-like services is required. Reaching new areas can promote new use cases/businesses/ services. As there is no viable alternative, those services will fully rely on this connectivity (e.g., Health services require high reliability and availability of the connectivity). Also, Maintainability requirements need to be high for them not being a cause for downtime. Moreover, the ecosystem needs to be designed in a fully reliable and resilient way in case of emergencies. As deployment cannot be defined through design, KPIs such as 'seconds of system downtime upon handover' could be implemented.
	User experienced data rate [Mb/s]	0.1 –25 Downlink/ 2 Uplink	Good quality video streaming should be delivered (not extreme experience). The data rate refers to a single UE, measured on the device. Based on current standards, from 0.1 (sensor data) to 25 Mb/s (4K video, based on current video requirements) are the expected bit rates, at least for Downlink. It may be revisited based on the evolution of video standards by 2030.

	Connection density [devices/m²]	0.1	Connection density is not a stringent requirement, as it does not target massively connected deployments. Also, connection density for rural areas are low. However, urban settings could require 0.1 devices/m², in case of crisis scenario.
	Coverage [%]	- Up to 10-15 km range (cell radius) for TN - 99.9% earth human environment on earth area coverage with integrated networks	Coverage means both extending the range of terrestrial networks, reaching larger cell size, but also the percentage of coverage of a given area, combining the different types of access, TN and NTN.
	Mobility [km/h]	up to 120	Mobility related to seamless handover between TN and NTN. It should support terrestrial vehicle speeds.
Positioning & New Capabilities	Location accuracy [m]	Low (≈ 10)	Global coverage option is not prone to high accuracy requirements.
	Sensing [Y/N]	N	Sensing usually not needed, except for some specific cases (during a crisis to obtain information)
	AI/ML-related capabilities [Y/N]	N	AI services can be provided offline, utilizing big data analytics. It might require AI capabilities to tweak routes, or other outcomes to minimize disruption time.

Table 3-16: Ubiquitous Network KPIs

3.9.2 Earth Monitor / Sustainable Food Production

The use case builds on two use cases described in Hexa-X D1.2 and D1.3, Earth monitoring and sustainable food production. This use case involves a large deployment of sensors to monitor and protect the environment while managing risks to people and agriculture. Since the areas to be covered correspond primarily to rural/deep rural or uninhabited areas, the use case relies on the interconnection of terrestrial and non-terrestrial networks, as well as a myriad of devices.

It can be illustrated by two examples:

- Earth Monitor for Environment Protection: A global environmental monitoring system, powered by bio-friendly sensors, widely deployed, provides real-time data on critical environmental factors like weather, climate change, and biodiversity. This system, accessible even in remote areas, enhances weather/climate models, enables disaster early warnings, and safeguards ecosystems from illegal activities. Connectivity can be based on, for example, NTN, long-range terrestrial or local mesh networks.
- Earth Monitor for Sustainable Food Production: Addressing UN's SDGs like ending hunger and ensuring food security is crucial. Building on new tools such as Digital Twins to improve efficiency of agricultural production through real-time monitoring of micro-locations, optimized plant treatments, experimentation with various strategies, and the use of semi-autonomous ground robots. The synchronized digital representation of the physical world proves instrumental in optimizing agricultural production and managing threats. This use case involves transferring large volumes of data from underserved areas, emphasizing the need for close synchronization. This approach tackles pressing global challenges related to sustainability, global coverage, inclusivity, and opportunity.

The adoption of 6G for Earth monitoring signifies a substantial leap forward in our ability to safeguard and understand the planet's ecological well-being, inaugurating a new era of precision and efficiency in environmental protection. In particular, 6G provides:

- Near real-time monitoring of critical environmental aspects such as weather patterns, climate change indicators, and biodiversity metrics through data collected from multiple sensors.

- Reaching even the most remote and inaccessible areas, providing comprehensive coverage for environmental monitoring efforts.
- Enhancing the processing and analysis of environmental data, enabling more accurate and timely insights through integration with AI and machine learning algorithms.

3.9.3 Autonomous Supply Chain

To ensure a fully integrated autonomous supply chain, the demand of scoping, ordering, sourcing, packaging, routing and delivery must be automated using local and central AI agents continuously optimizing the process, for example, in relation to unexpected events such as natural events, disasters or political circumstances [HEX21-D12]. 6G will enable a fully automated supply chain, at reasonable cost and complexity. With global E2E lifecycle tracking of goods from production, shipping, distribution, usage and recycling; higher resource efficiency and reduced material and energy consumption can be achieved. The use of 6G-connected micro tags on goods can simplify tracking, customs, safety checks, and bookkeeping, allowing it to be done without manual interference.

6G's increased and ubiquitous coverage, low latency, and advanced connectivity capabilities make it a crucial enabler for the development and implementation of autonomous supply chain systems, ultimately leading to more efficient, agile, and resilient supply chain operations. In particular:

- Real-time monitoring and decision-making in the supply chain through fast data transmission.
- Minimal delay in data transmission, which is essential for tasks that require immediate response, such as autonomous vehicle navigation, order processing, and inventory management through low latency.
- Remote assistance, training, and visualization to enhance the autonomy and efficiency of the supply chain through integration with XR technologies.

3.9.4 Virtualization of Device Functionalities

Current handsets have evolved to become highly complex and precise machines. The numerous functionalities that a handset can offer (and on which many of us rely on) require highly intricate design and a myriad of raw materials sourced from all over the globe, to name a few. As a result, most of the product’s footprint comes from production stages, rather than usage stages. This is highly detrimental for the environment considering that the average lifespan of users’ handsets is only a couple of years, further contributing to the already huge problem of e-waste and resource depletion.

As numerous services are being migrated to the cloud ecosystem, it is foreseeable that many handset functionalities might follow the same path. As 6G network availability and trustworthiness will increase, it would then be possible to shift processes and/or storage from the handset to the cloud, while still providing a seamless experience for the end-user. The ecosystem’s evolution (radio, core, cloud) is key to the enablement of this use case.

Virtualizing functionalities and relying on cloud ecosystems allows handsets to evolve into less complex machines, creating several benefits and opportunities. First, as materiality in terminals will be reduced, it allows to decrease the environmental impact (e.g., e-waste, resource depletion, complexity of recycling). Second, it can untap new markets and/or allow new business models to be deployed at reduced cost. Examples of such can be (a) subscription-based phones (shifting responsibility to manufacturers rather than users), (b) producing a single handset model, and paying extra based on the processing needs of each user, or even (c) promoting handset modularity. Third, producing cheaper handsets will also contribute to digital inclusion. Moreover, handsets could also be easily adapted to the special requirements of the user (e.g., the elderly). Finally, other foreseeable benefits are higher energy efficiency/longer-lasting batteries, decreased supply chain risks, and the ability to upgrade the handset’s software instantly on the cloud. These benefits will have to be balanced with the possible side effects on the cloud and impact on deployment, to guarantee that global balance is favorable for sustainability.

3.9.5 Digital Sobriety and Enhanced Awareness

The energy consumption and contribution to GHG by the ICT industry is considerable and expected to keep growing due to society's increasing dependency and pervasiveness of these services, despite the technical efficiency gains achieved. Unfortunately, advances in energy efficiency have been primarily led by industry, usually leaving the end user out. Furthermore, it has not provided the information necessary for creating awareness of the end user's digital footprint, nor the tools to manage this behaviour.

Knowledge is power. Therefore, this use case relies on AI capabilities and a deeper understanding of the impact of different elements throughout the value chain to (1) unravel the E2E energy consumption (including networks, applications, and devices), (2) the particular settings affecting that energy consumption (e.g., data route chosen, the country's energy mix where the service is running), as well as (3) incorporating information regarding the environmental impact of different elements (e.g., sourcing, life-cycle footprint). Currently, this information has not been made available nor deemed relevant for the end-user's experience.

Building on the availability of this information to create awareness of the environmental impacts each user is responsible for, the end user will have the ability and freedom to adjust the trade-off between the quality of service and environmental footprint. An example of such is to explicitly show metrics such as "instant carbon footprint" while watching a video, coupled with suggestions on how to manage the total impact (e.g., lower video resolution, accept higher latency, avoid paths involving non-circular material usage, or even switching providers). Making this information transparent, allows the user to evaluate the trade-offs between service performance and quality from one side, and the environmental impact on the other side.

3.10 Trusted Environments Use Case Family

3.10.1 Human-Centric Services (Representative Use Case)

3.10.1.1 Description

This use case genuinely focuses on the human at the centre of a wide range of 6G services. Human-centric services demand the use of trusted environments where privacy and reliability are key characteristics to make the services trustable by the public. Some examples of these services are:

Precision healthcare: health monitoring, diagnosis, and therapy will enable personalized diagnosis and treatment. A 6G tele-medical paradigm can be enabled by in-body sensing and AI/ML-based analytics in conjunction with wide-area connectivity.

Safe environments such as kinder gardens, schools, homes, day-care, workplaces, or hospitals will be of help to establish well-being, safety, inclusion, autonomy for children, elderly, and people with disabilities. Sensing and AI/ML compute for accurate localization, spatial- and situation-awareness as well as for appropriate alerting will help to avoid physically risky situations and accidents as well as socially critical situations and potential incidents. Prevention and avoidance can also be adaptive to the type of the environment; safety of children on a playground vs safety of patients in a hospital differ in aspects and requirements. Personal automation services add onto localization and situation awareness in that sensing can trigger adaptations of the surroundings. For instance, ramps can be made available when a person in a wheelchair is about to enter a building.

Public safety services during big events: at big public events such as football matches, big concerts, or parades, public safety services may use human-centric information, e.g., location, personalized data, and emergency contacts, which need to be anonymized and privacy-protected.

Human-centric services impose very high privacy requirements not only comprising consent management but even more so technical solutions such as anonymization, pseudonymization, advanced information coding, or additive homomorphic technologies. Moreover, solutions to privacy protection cannot exclusively reside in the application domain and must be built into the 6G system.

To guarantee the safety of thousands of people at a big event or of hundreds of workers on a construction or a chemical manufacturing site, the 6G network deployment needs to achieve very high service availability or service reliability.

Problem(s) to be Solved/Challenges

- Providing extended access to **high-end health monitoring and diagnosis** even for in-body or on-body sensing as well as to access to **accurate therapy**.
- Safe environments offer **well-being, mental health, safety, inclusion, and autonomy** to children, elderly, persons with disabilities, and other social groups.
- **Safety, health, peace of mind** can be established for hard-hat workers on construction and industrial sites as well as to visitors of big public events.

Why 6G is needed

Due to the private character of the data, **privacy protection** is of key for this use case. Privacy will be enabled by new techniques such as local anonymization, pseudonymization, advanced information coding and additive homomorphic technology. In addition, solutions to protect physical privacy are required for a body-subnetwork of sensors, actors, and evaluation devices.

For human-centric services, **service reliability** is key to obtain users' trust. Besides, in scenarios such as safe environments or public safety, a high service availability is crucial to avoid catastrophic situations.

Use of integrated sensing and AI/ML compute are key technology components for some service scenarios. Sensor device connection density for safe indoor environments may exceed the 5G KPIs.

3.10.1.2 Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (costs)
Environmental	• If used for smart services, potential reduction in GHG emissions resulting from reduced commuting and optimized use of travel infrastructure • If used for healthcare, potential reduction in medical waste	• Increased material consumption for new devices and network deployment • Energy consumption to support AI/ML and e-health operations, storage, and processing of extensive healthcare data • Electronic waste from disposal of body sensing and computing devices
Social	• Increased availability of human-centric services • Enhanced safety • Enhanced freedom of movement for people needing continuous health monitoring (outside hospitals) and thus, quality of life • Enhanced trustworthiness of digital services • Optimizing the time of care (relevance of transportation)	• Privacy risks from monitoring humans • Potential risks for trustworthiness/safety in case of hacking
Economic	• Economic efficiency improvements and reduced costs for human-centric services • Economic predictability from creating trust with human-centric services	• Pressure on demand side can impact efficiency • Safety degradations from new risks related to new services

Table 3-17: Human-Centric Services Sustainability Aspects

Environmental

This use case has the potential to reduce carbon emissions in services such as smart healthcare and education by reducing the necessity to travel/commute to benefit from these services. However, this potential reduction highly depends on travel trends and changes in people's behaviours. In-body sensors and AI/ML compute can lead to energy-efficient monitoring and more targeted healthcare practices contributing to reduced energy consumption and medical waste related to unnecessary medical procedures, tests, and treatments. However, this use case also increases the number of deployed devices and the amount of infrastructure, which would increase the material and energy consumption. The disposal of sensors and computing equipment could also result in increased waste.

Social

Human-centric services are a clear example of the social values that 6G can deliver. For example, precision healthcare grants the possibility to live life more freely, relying on AI and measuring capabilities to predict any issues on time. It will also enable people outside urban areas to access these services. Also, the creation of safe environments can have a great impact on the liveability of cities, risk management/prevention, and reduction of accidents to name a few; and consequently, on the quality of life for humans.

However, collecting and handling vast amounts of personal data can have severe repercussions in case of cyber-security breaches (for example), or the trust of the system as a whole.

Economic

Improved economic predictability can arise from creating trust with new human-centric services. There can be economic efficiency improvements and reduced costs achievable by the human-centric services. On the cost side, there can be pressure on the demand side which can impact economic efficiency. Safety degradations are possible due to new risks related to new human-centric services.

3.10.1.3 Example Service Scenario

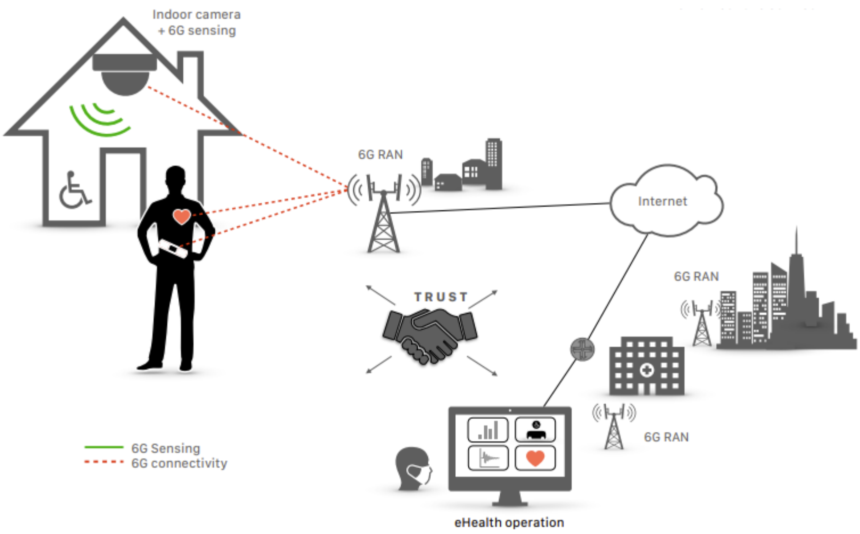

Figure 3-9: Human-Centric Services Example Scenario

Precision Healthcare

Precision medicine is "an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment, and lifestyle for each person," according to the Precision Medicine Initiative [PMI]. The new and future possibilities of health monitoring (through numerous wearable devices, topical, implanted, injected, or ingested sensors, and ambient devices), diagnosis and therapy will enable personalized diagnosis and treatment. Bodily and sensory reactions like organ malfunction and pain can be represented and analysed in the digital domain. A 6G telemedical paradigm will be enabled by in-body sensing and analytics in conjunction with a wide area connectivity option.

Obviously, very high privacy requirements including the need for local anonymization and pseudonymization will require local protected signal processing capabilities. Logging activities and environment of persons might require access to information on the Cyber-Physical Environment. Application domain-specific regulations for in-body devices such as implants or injectables as well as for on-body medical wearables need to be considered.

Safe Environments

Environments like kinder gardens, day-care, hospitals can be trusted environments to ensure **quality of life** for children, teenagers, elderly, persons with disability, and other social groups. Quality of life means health, well-being, safety, both physically and socially, inclusion, and for instance for elderly autonomy in their daily life.

Safe environments can be created by spatial awareness based on high-resolution sensing, e.g., cameras, radar, IR-sensors, localization, mapping, tracking, and AI/ML compute.

Tripping over objects or getting in the way of autonomous robots can be avoided by consequential alerting, an autonomous robot getting out of the way, and sending help if needed.

A patient about to collapse in an overcrowded emergency room can be helped by immediately sending a nurse to the patient.

Public Safety Services during Big Events

Localized situations of rising emotion, subtle violence, and upcoming panic in a big event may be detected early by anomalies in behaviour derived from body gestures, facial expressions, and sound analysis, and may be de-escalated by announcements, by concentrating the security personnel on spot, and by accompanying aggressive individuals off the event ground.

3.10.1.4 Deployment Aspects

Environment & Type of Deployments	Precision healthcare and many scenarios in environments that shall be hazard-free are envisioned as indoor deployments within urban, sub-urban or rural areas, e.g. individual homes, hospitals, kinder gardens, elderly houses, or workplaces. These can be served by public or private local sub-networks embedded in the wide-area network.
User Devices	Zero-energy sensors and wearables: examples are in-body devices such as implants or injectables, on-body medical devices.
Constraints and Challenges	Prioritization of privacy/security and reliability/availability: Private data, sensing data and derivates of those need to be confined to the trusted environment and inaccessible for other purposes than declared and consented. Service continuity: service continuity between local sub-network and wide-area network for authentication, E2E encryption, or personal data access granted by individuals.

Table 3-18: Human-Centric Services Deployment Aspects

3.10.1.5 Requirements and KPIs

Requirements

- **High privacy protection:** due to the private character of the data, privacy protection is of key for this use case. This privacy will be enabled by new techniques such as local anonymization, pseudonymization, advanced information coding and additive homomorphic technology. In addition, physical privacy solutions are required for a body-subnetwork of sensors, actors, and evaluation devices.
- **High service reliability:** when talking about human-centric services, the reliability of the services is key for user trust. Besides, in scenarios such as safe environments or public safety, a high service availability is crucial to avoid catastrophic situations.

KPIs

	KPI	Target Range	Comments / Justification
Communication	User experience data rate [Mb/s]	–	
	End-to-end latency [ms]	< 250 < 1000	For AGVs and care robots, e.g. in homes for the elderly and in hospitals. Initiating an intervention in case of an evolving critical situation in a crowd.
	Reliability [%]	99.9 – 99.999	High service availability is key for this use case.
	Connection density [devices/m^2]	1 to 10 < 0.001	Indoor per floor Outdoor
	Coverage	–	
	Mobility	pedestrian, slow vehicular	
Positioning & New Capabilities	Location and positioning accuracy [m]	< 10 < 0.3 to < 1 < 0.1	Location accuracy Positioning accuracy Relative positioning accuracy, e.g. collision avoidance
	Sensing-related capabilities [Y/N]	Y	Relevant for most of the scenarios
	AI/ML-related capabilities [Y/N]	Y	Relevant for most of the scenarios

Table 3-19: Human-Centric Services KPIs

3.10.2 Industrial Sensors Network for Safe Production & Manufacturing

Safety at the factory floor is critical for workers. Sensors deployed in a factory can help to alert workers of dangerous areas or situations. A good example is light curtains [IFM][Sic20], where a transmitter sending parallel beams towards a receiver is installed around dangerous or sensitive equipment. If one or more beams are broken, a signal or alarm can be generated.

To ensure the correct functioning of these critical safety measures, a highly reliable network beyond what 5G can provide will be needed (a trusted environment).

3.10.3 Wireless In-Vehicle Network

This use case involves replacing in-vehicle wiring with wireless connectivity to address current problems with design and installation complexity, complicated and expensive maintenance, vehicle weight, cost and difficulty during the introduction of additional in-cabin features and autonomous driving features. Wireless in-vehicle network can bring significant benefits varying from manufacturing to maintenance and operation cost reduction. It is also expected to ease the introduction of new features e.g., new backseat entertainment system and new sensors.

Due to the privacy of the data and the need for high reliability in vehicles, trusted environments beyond 5G are needed for this use case.

3.11 Use Cases Summary

To instruct the design and the development of the 6G system, Hexa-X-II has identified six use case families, outlined in Section 3.4, as well as one representative use case per family. These representative use cases have been analysed in greater detail in the previous sections.

Why 6G is needed

A set of requirements as well as a set of relevant KPIs is presented in Part 5 "Requirements and KPIs" for each representative use case. Characteristic requirements refer to technology components and preliminary sustainability aspects considered indicative for 6G. Furthermore, the analysis of representative use cases has resulted in a set of KPIs of which some exceed the IMT-2020 5G KPIs and indicate the need for 6G. Table 3-20 summarizes "why 6G is needed" for each of the representative use cases by listing the characteristic requirements and the KPIs reaching beyond 5G.

Use Cases	Characteristic Requirements Note 1	KPI reaching beyond 5G Notes 2, 3
Seamless Immersive Reality	• AI/ML and compute-related capabilities • Sensing-related capabilities for some scenarios • High privacy protection demand	• User-experienced data rate of 250 Mb/s • Positioning accuracy of better than 10 cm • Wide area capacity of 20 $Mb/s/m^2$ • Better than 10 ms E2E latency for some scenario aspects.
Cooperative Mobile Robots	• Enhanced local ad hoc connectivity: device-to-device communication capabilities and distributed communication resources • AI/ML-related capabilities: federated learning and split AI/ML compute • Sensing and positioning capabilities integrated into the radio interface	• For some applications, in a localized area, E2E latency of better than 0.8 ms • For some applications, in a localized area, communication service availability of up to eight 9s
Network-Assisted Mobility	• Sensing-related capabilities with sufficient detection probability and resolution • High connectivity service availability	• Connectivity service availability of 99.99%, i.e., probability to get service fulfilling latency within defined service space • Absolute positioning accuracy of better than 1 m with 99.9% reliability in 99.9% of defined service space • Relative positioning accuracy of better than 10 cm

Realtime Digital Twins	• Sensing-related capabilities, i.e. network-sensing, and positioning accuracy • Secure, low-cost, and energy efficient connectivity	• Single digit ms E2E latency • Reliability of seven 9s • Connection density in some cases up to 10^7 devices/km^2 • Positioning accuracy of better than 10 cm
Ubiquitous Network	• Service coverage "anywhere for everyone" by integration of TN and NTN and of multiple networks • Trustworthy-by-design network infrastructure	• Service coverage of 99.9% earth landmass area
Human-Centric Services	• High privacy protection demand • High service reliability	• Indoor per floor connection density of up to 10 devices/m^2. • Location accuracy of better than 1 m • Service availability of up to five 9s
Note 1: For all representative use cases "characteristic" requirements are listed. Characteristic requirements are those requirements, of all requirements listed in Part 5 of the use case analyses, that are considered indicative for 6G from a technology or sustainability point of view. **Note 2**: For all representative use cases KPIs are listed if they exceed IMT-2020 KPIs. **Note 3**: The IMT-2030 capabilities are specified as "research targets" [IMT2030]; the KPIs here are E2E KPIs as well as use case-specific and may require refinements and capability differentiation within and beyond this deliverable.		

Table 3-20: Why 6G is needed: characteristic requirements and KPIs reaching beyond 5G KPI

Spectrum Considerations

In general, spectrum characteristics and considerations as outlined in Section 5.3.5 of [HEX223-D11] are applicable for selecting a proper frequency range (FR) for the deployment of a certain use case and a given service scenario. Currently specified by 3GPP are FR 1 (0.41–7.125 GHz) and FR 2 with its two sub-ranges FR 2-1 (24.25–52.6 GHz) and FR 2-2 (52.6–71 GHz) [38.101]. Further ranges currently under discussion include 7–15 GHz and 92–300 GHz (sub-THz). Important to note is that the following statements are not meant to be exclusive; deployments of use cases within specific frequency ranges depend just as well on non-technical aspects like licence availability or facility ownership.

To achieve reliable wide-area coverage which is specifically important for representative use cases *network-assisted mobility* and *ubiquitous network* low-band spectrum is essential, preferably very low below 1 GHz. This can be complemented by NTN systems in L-band (1–2 GHz) or S-band (2–4 GHz). Since achievable data rate and capacity in those deployments is limited, higher ranges in FR 1 and new potential bands up to 15 GHz could supplement very-low band deployments to achieve a better capacity, for instance in line-of-sight (LoS) scenarios of *network-assisted mobility* in urban environments. Furthermore, satellite systems in higher frequency ranges in Ku/K/Ka bands (12–40 GHz) might be an option to connect remote regions with a higher data rate.

For use cases in confined areas like *cooperating mobile robots* and *human-centric services* frequency ranges of 3–15 GHz and small-cell deployments could be used. Additionally, FR 2 or local sub-THz deployments can be used to meet even higher data rate and capacity requirements, like for some aspects of the *seamless immersive reality* representative use case.

Sustainability in 6G

An initial qualitative sustainability analysis referring to values of environmental, social, and economic sustainability has been presented for all representative use cases in the "Sustainability Analysis" section referring both to positive impact as well as to negative consequences, i.e., sustainability handprint and footprint.

Outlook

Further evaluation of the representative use cases will be performed and related refinements will be made in upcoming deliverables. A key objective is to evolve the sustainability analysis in particular with respect to an in-depth stakeholder analysis. Ongoing regulatory work, specifically on the spectrum, will be integrated continuously, and the potential impact of the representative use cases on society and the planet will be assessed in further detail. The development of the new concept of Key Value Indicators (KVIs) will be continued and will, as a complement to KPIs, serve to guide the design of the 6G blueprint.

4 Channel models

4.1 Introduction

After defining a complete set of use cases, the next step to take in the design process is to identify which channel models can apply to the use cases and cover their demands from a radio perspective. Understanding and identifying the channel characteristics is a key milestone for engineers to be able to select or design the appropriate frequency, power, modulation, coding, antenna, and protocol for the future 6G system.

The goal of this chapter is to present a state-of-the-art (Section 4.3 and 4.4) of the current propagation channel models available and conclude how these channel models could be adopted in different scenarios related to the 6 Hexa-X-II representative use cases introduced in Chapter 3, while identifying any gap or need for new channel models or enhancing existing ones (Section 4.5).

4.2 Channel models: Definition

Propagation channel modelling is a vast scientific and technical area with many contributions from research organizations and scientific cooperations, such as European research projects and standardization bodies. This document will mainly focus on channel models defined by either European research projects or standardization bodies.

In general, far-field conditions are always assumed in current propagation channel models. This means that the propagation channel between a transmitter and a receiver can be modelled by a set of rays. For example, in Figure 4-1, the propagation channel from Base Station 1 (BS1) to Mobile Station 1 (MS1) is modelled using two rays: the *blue one* represents the direct path, *the dashed red one* represents the reflected ray on building B.

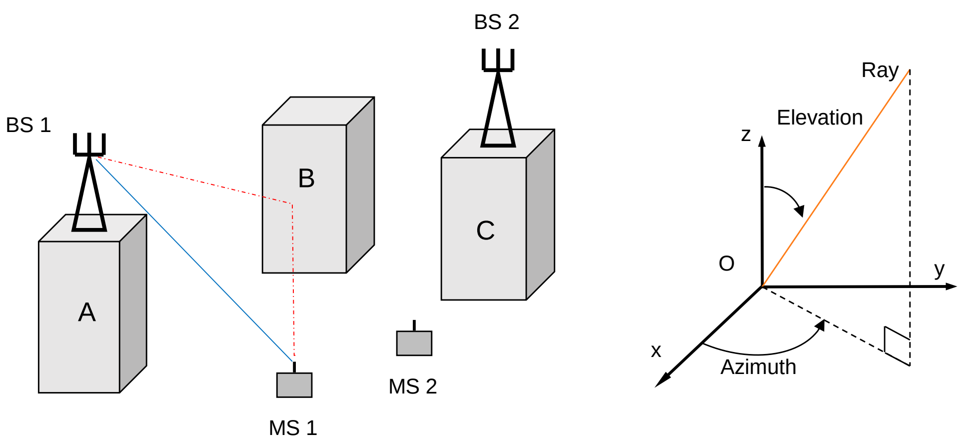

Figure 4-1: Illustration of Ray-based Channel Models

A ray is defined by *geometrical* and *electromagnetic* features:

- The *ray geometrical features* define the ray length, which is the distance travelled by the electromagnetic wave, and the ray 3D orientation at the transmitter and receiver. The 3D orientation is given by the elevation and azimuth as illustrated by Figure 4-1.
- The *electromagnetic features* are defined as the complex channel coefficients depending on the antenna polarization at both links. The channel coefficients give the attenuation undergone by a ray, due to the

travelled distance and/or to the interaction with the environment such as the reflection on a building facade, the diffraction by an edge building or the penetration through a wall.

A set of rays is also called a set of paths or sub-paths depending on the channel model terminology, but multi-paths or set of rays refers to the same mathematical entity. There are two different approaches to generating the set of rays: the statistical geometrical approach and the deterministic approach, as outlined in Section 4.3 and Section 4.4.

A *propagation channel model* can be characterized as *static* or *dynamic*. A *static propagation channel model* provides a constant set of rays. From a strictly theoretical point of view, a set of rays with constant properties models a static channel and cannot model vehicle displacement. Practically, a constant set of rays also models a Wide Sense Stationary situation as the mobile motion over a short distance can be simulated by changing the ray phase. A *dynamic propagation channel model* is not limited to a short distance and also supports spatial or temporal non-stationarity, for instance in case of blockage. For such situations, a channel model needs not only to simulate a constant set of rays but also to integrate a dynamic ray birth-dead mechanism for non-stationary propagation channels.

A *propagation channel model* can be also characterized as a *single-link* or *multi-link*. A *single-link model* provides the set of rays between one transmitter and one receiver but does not support multi-point communication schemes such as distributed MIMO, Reconfigurable Intelligent Surfaces (RIS) or relaying. A *multi-link propagation channel model* is able to generate coherently several links. Figure 4-1 illustrates an example scenario with two mobiles MS1 and MS2 and two base stations BS1 and BS2. A *multi-links model* shall be able to simulate coherently the links X-Y, X and Y being BS1, BS2, MS1 or MS2. The capacity to generate coherent multi-links is called *spatial consistency*.

Furthermore, *propagation channel models* not only differ from each other by the targeted environments and frequency ranges but also by the functions implemented to support non-stationarity and spatial consistency. In the following, the current channel models are described while underlining the environment, the frequency ranges and the special functions implemented.

4.3 Statistical Geometrical Models

In this type of *propagation channel models*, the set of rays is defined by statistical distributions, mathematical equations, or geometrical considerations. Originally, these models were called *Geometrical Stochastic Channel Model* and were based on a pure geometrical approach. The models developed within European COST actions (COST 259[COST259], COST 273[COST273], COST 2100[COST2100]), are the most well-known examples.

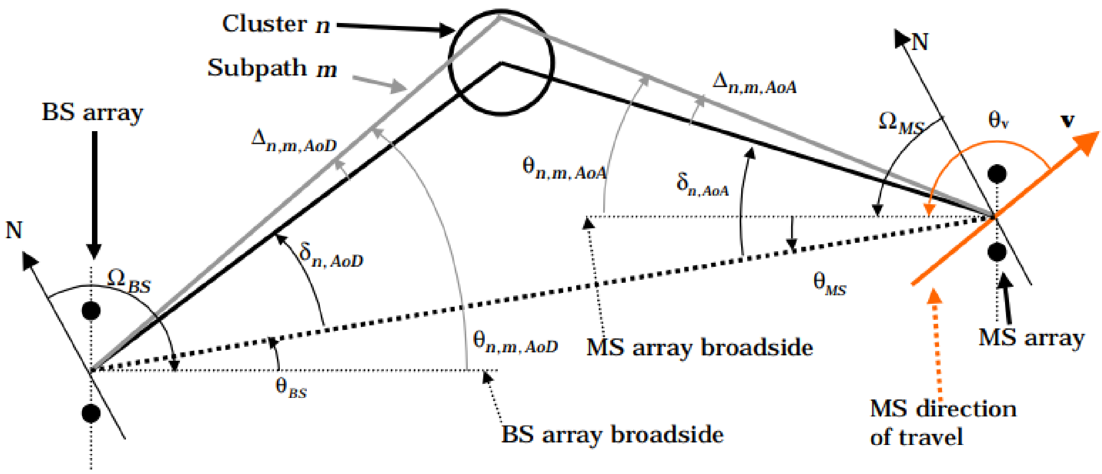

Figure 4-2: Illustration of the 3GPP-SCM [25.996]

The geometrical approach was adopted for the first time in 2003 by 3GPP with the Spatial Channel Model (SCM) referenced as 3GPP 25.996 channel model [25.996]. The scattering environment between the BS and the UE was modelled by a number of clusters that were split into twenty equal power sub-paths arriving at the same delay as shown by Figure 4-2. The SCM model was limited to three environments and defined only at 2 GHz but it laid the foundations of successive channel models developed by the 3GPP or by the European projects WINNER [WIN05-D5.4], WINNER II [WIN207-D112], WINNER+ [WIN+10-D53], METIS [MET15-D14] and mmMagic [MMM17-D22]. This explains why these models are sometimes called 3GPP-like or Winner-like channel models.

Statistical geometrical channel models have very similar procedures to determine the ray features. Firstly, path loss and large-scale parameters are generated for specific environment and propagation conditions, then the set of rays is generated according to mathematical equations defined as a function of the path-loss and large-scale parameters. Figure 4-3 illustrates the different steps of the ray generation. The Shadow Fading (SF) and K factor are parameters used with the path loss model to compute the propagation channel attenuation. The cross-polarization ratio (XPR) gives the additional attenuation when the receive antenna polarization is orthogonal to the transmit antenna polarization. The Delay Spread (DS) and Azimuth Spread (AS) characterize the frequential and spatial diversity. The model may be improved by including additional blocks implementing special functions such as the blocking effect.

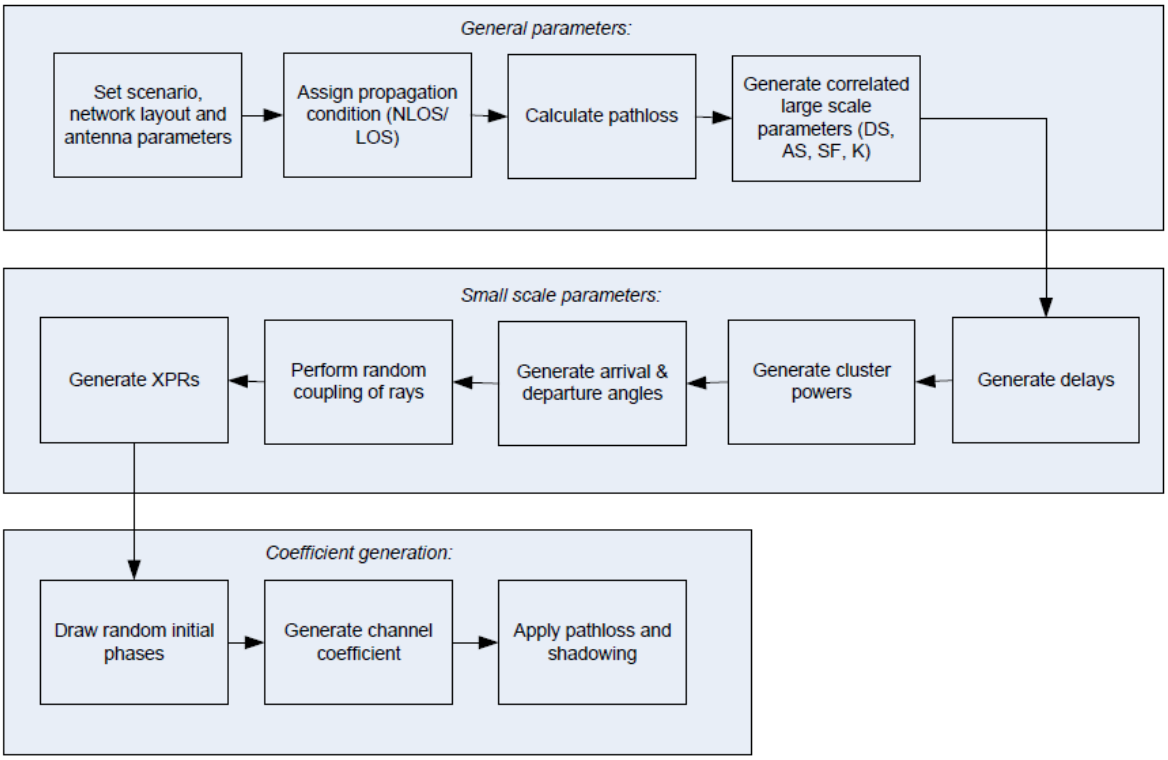

Figure 4-3: Ray Generation in Geometrical Channel Model

Table 4-1 lists the different geometrical channel models that have been proposed by ITU-R, 3GPP or European research project Winner II, Metis and mmMagic. Quadriga is an implementation that was developed by the Fraunhofer Institute in the framework of the mmMagic project. It supports the mmMagic model and the 3GPP 36.873 [36.873] and 38.901 [38.901] channel models. The latest channel models use spatial consistency features which able to simulate the trajectory of a mobile experiencing spatial non-stationarity. It, however, does not cover the spatial consistency between different communication points. For instance, it is not possible to simulate correlated links when the mobile receives information from more than one transmitter in for example scenarios such as cooperative communication, relaying, intelligent reflective surface, etc.. Additionally, these models were developed for wireless communication performance evaluation and not for other services such as localization and sensing e.g., these models do not consider the scenario where the transmitter and receiver are located at the same point which is the case for mono-static sensing applications.

Channel Model	Scenarios	Frequency (GHz)	Special Features	First Release Year	Reference
ITU-R M.2135 (Winner II Extension)	InH (LOS/NLOS), UMa (LOS/NLOS), UMi, (LOS/NLOS/O2I), RMa (LOS/NLOS), SMa (LOS/NLOS)	2-6		2009	[M.2135]
3GPP 36.873	InH (LOS/NLOS), UMa (LOS/NLOS/O2I), UMi, (LOS/NLOS/O2I), RMa(LOS/NLOS)	2-6	3D	2013	[36.873]
METIS	UMi (O2O, O2I), UMa (O2O, O2I), RMa, indoor office and shopping mall, highway	up to 70	3D, dual mobility, blockage	2015	[MET15-D14]
3GPP 38.901	InH-Office (LOS/NLOS)InF (LOS/NLOS) UMa (LOS/NLOS/O2I), UMi-Street Canyon (LOS/NLOS/O2I), RMa(LOS/NLOS/O2I)	0.5 - 100	3D, spatial consistency, blockage.	2017	[38.901]
ITU-R M.2412	InH (LOS/NLOS), UMa (LOS/NLOS/O2I), UMi (LOS/NLOS/O2I), RMa(LOS/NLOS/O2I)	0.5 - 100	3D, spatial consistency, blockage	2017	[M.2412]
QuadriGA	Same as 38.901	Up to 80 GHz	Same as 38.901, new calibration UMI, InH,	2017	[MMM17-D22] [QDR]

Table 4-1: Statistical Geometrical Channel Models.[1]

4.4 Deterministic Channel Models

Deterministic propagation channel models, also called site-specific channel models, use a geographical database or digital map that describes the environment. These channel models do not contain any statistical components as was the case for statistical channel models.

Ray tracing or ray launching are the most popular *deterministic propagation channel models* to evaluate the performance of wireless radio interfaces or to predict the coverage area. Ray launching differs from ray tracing by the algorithm implemented to compute the ray geometrical features, but has the same configuration parameters, requires the same inputs and provides the same outputs. In this section, the term ‘ray tracing’ is used, but it covers ray launching as well. Ray tracing uses a geographical database to compute all possible rays i.e., direct, reflected, transmitted, diffracted, diffused paths, between two or more points such as transmitter, receiver, Reconfigurable Intelligent Surface (RIS), relay, etc. Figure 4-4 gives an example of ray tracing simulation.

[1] UMi: Urban Micro, UMa: Urban Macro, RMa: Rural Macro, InH: Indoor hotspot, InF: Indoor Factory, SMa: suburban Macro, O2I: Outdoor-to-Indoor, LOS: Line-of-Sight, NLOS: non Line-of-Sight

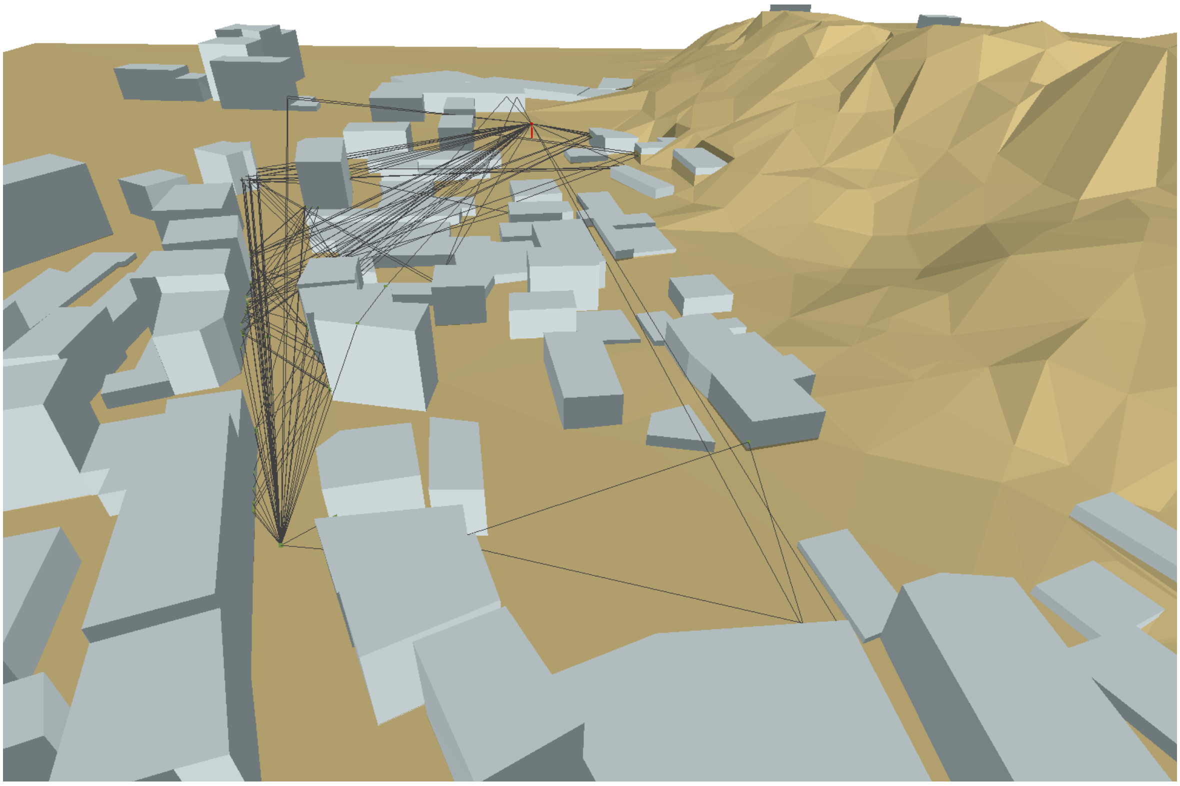

Figure 4-4: Ray Tracing Illustration

The ray amplitude and geometrical features are given by physical laws according to the interaction type between the electromagnetic (EM) wave and the environment. For instance, the direct path amplitude is given by the well-known free space path loss equation, the diffracted path amplitude is given either by the knife-edge diffraction theory or by the Geometrical Theory of Diffraction/Uniform Theory of Diffraction, the reflected or transmitted path amplitude is given by the Fresnel equations. Compared to other physical phenomena losses, reflection and transmission losses depend on two material properties, the permittivity and conductivity, that may be frequency dependent. Hence, ray tracing shall include a material table indicating the material permittivity and conductivity and, if necessary, how these parameters change with frequency. Many simulations refer to the International Telecommunication Union Radio-communication (ITU-R) P.2040 model [P2040]. This model, however, is only valid up to 100 GHz. A recent study in Hexa-X [HEX23-D23] proposes to extend the coefficient to up to 300 GHz for applications using sub-THz frequencies.

Ray tracing has many advantages as they are simply described by the geographical database and the locations of for example transmitter, receiver, and RIS. Hence, there is no need for a long description to provide path loss, large-scale parameters statistical distribution, and large-scale correlation. The spatial consistency is given by the geographical database. The simulation point number is not limited under the condition that the configuration does not exceed the computer processing limits. Distributed MIMO, RIS or any other deployment scheme including multi-point communication is easily simulated. Ray tracing does not need measurement to be calibrated but requires careful upstream work to determine the permittivity table and adjust the proper geographical accuracy level according to the simulation requirements.

Geographical databases are much simpler than the reality. For instance, buildings are often modelled by concrete parallelepiped. Consequently, ray tracing is not able to compute all rays and does not simulate very well the small-scale fading generated by multi-path interferences. When compared to the statistical model generation methodology, ray tracing can simulate large-scale parameters and clusters but not sub-paths. This is the reason why pure deterministic ray tracing is often coupled with a stochastic part. Figure 4-5 illustrates the map-based hybrid channel model proposed as an option by [38.901].

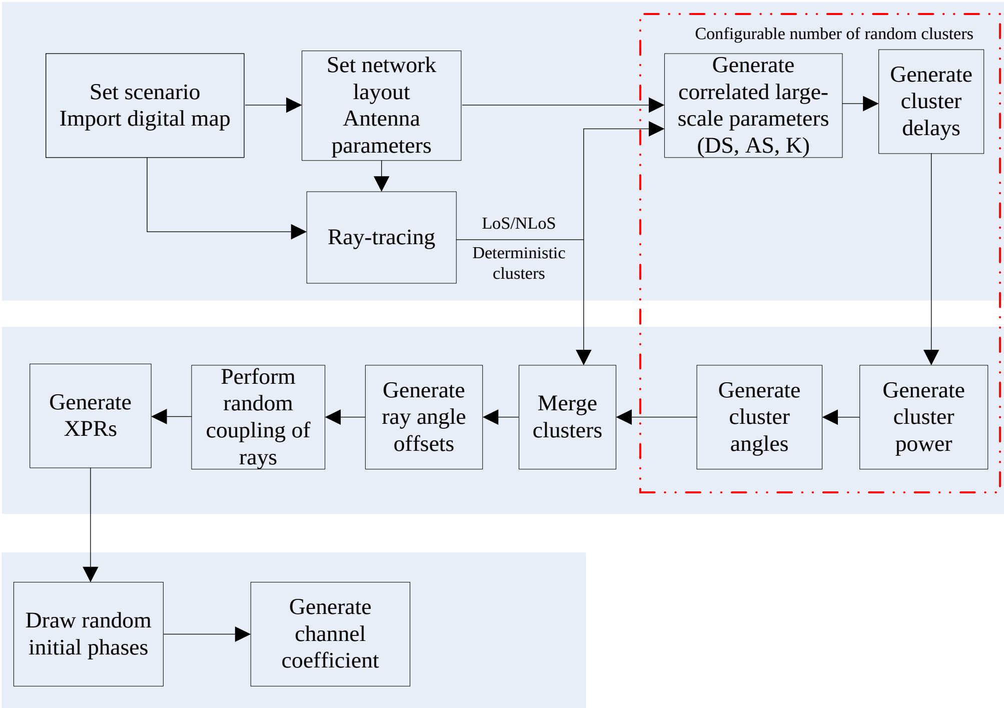

Figure 4-5: Map-based Hybrid Channel Model

The 3GPP TR38.901 map-based option is inspired by the work achieved in the European research project Metis [MET15-D14], but it does not propose any digital map as was the case in the Metis project for an urban environment, an indoor office and a shopping mall. Therefore, the 3GPP TR38.901 model is mainly used for the statistical channel model defined in the previous section 4.3.

Another example of a hybrid deterministic channel model is given by the IEEE 802.11ay channel model. This model is based on the existing channel models for 60GHz WLAN systems [802.11ad], extensive ray-tracing simulations and the results of the European-Japan project MiWEBA [MWE16-D51]. The IEEE802.11ad channel model does not define a frequency range but the measurement campaigns and ray tracing simulation targeted mainly frequencies around 60 GHz. The proposed environments are a living room, enterprise cubicle, conference room, open area, street canyon and hotel lobby.

Deterministic channel model or hybrid deterministic channel model have many advantages and can support many use cases. However, ray tracing may not be straightforward to implement compared to statistical channel models. Implementing a 2D-ray tracing based only on reflection in a simple environment such as an empty room delimited by four walls, a floor and a ceiling is quite simple. Implementing a 3D-ray tracing based on reflection, diffraction, and diffusion in the case of rough surfaces in a complex environment is much more difficult and may be time-consuming particularly if geographical size, the number of objects or mobility of the objects increases or varies. This explains why this kind of models has not been yet widely adopted by standardization bodies.

Another hybrid approach is the stored channel approach. A stored channel model at 140 GHz from measured and ray launching-assisted channels is presented in Section 3.2 of [HEX23-D23] and can be accessed from [DHK23]. This channel model is based on channel measurements performed in an entrance hall, and outdoor scenarios such as suburban, residential, and city centres from 140 GHz to 144 GHz. The transmitter side is equipped with an omnidirectional bicone antenna and the receiver side has a rotator-mounted directional horn antenna resulting in single-directional multipath data of the measured links. These data are then augmented using a measurement-based ray launcher to estimate the double-directional multipath data containing the path gain, angle-of-arrival, departure, and delay [DH23, DKH22]. The stored channel model enables the reproduction of measured channels for any specified antenna type of interest. The channel frequency response is determined by using the multipath data and the complex radiation patterns of the specified antenna. Random snapshots of these frequency responses can be generated by introducing uniformly distributed random phases for each path.

4.5 Channels Models and Hexa-X-II Use Cases

The comparison between the propagation channel model state-of-the-art and the Hexa-X-II use cases highlights some lacks for the current propagation channel models and suggests the following enhancements:

- Model extension for frequencies above 100 GHz: Current models are limited to 100 GHz whereas some use cases plan to use frequencies above 100 GHz.
- Special feature implementation for JCAS: Channel models were developed for wireless communication performance evaluation and not for sensing applications. For instance, there is a need to model the radar cross-section of urban objects or to define channel models with the transmitter and receiver located at the same point.
- Spatial consistency improvement: Spatial consistency is a key feature for sensing applications to resolve different objects from the time-angular channel impulse response. It is also a key feature for multi-point deployment schemes.

The propagation channel modelling work in Hexa-X I and II is focused on the first bullet with the extension of ITU-R and 3GPP model above 100 GHz.

5 Business Models for 6G Ecosystem

5.1 Introduction

The goal of this chapter is to expand the use case developments by deriving initial business models for some of the representative use cases presented in Chapter 3. To derive business models including revenue models, is the ultimate goal of a use case. They capture the value propositions of the use cases' business ecosystems and specify business opportunities for single stakeholders.

Section 5.3 reviews the most used tools and templates for business models and provides a complete state of the art of the current business models used in the telecom sector. Section 5.4 outlines the methodology that will be used to develop the business models of the Hexa-X-II use cases. Finally, in Section 5.5 the business models for the selected representative use cases from Chapter 3 are presented.

5.2 Business Model: Definition

A Business Model describes how a company creates, captures, and delivers value. The business model concept is rooted in the strategic management field, and it reflects the main strategic components in a firm´s competitive landscape such as opportunity, value, and advantage. A business model is a means to achieve the implementation of a strategy [DDO+10]. Nevertheless, there is not a commonly accepted definition of a business model.

In general terms, a business model is often described as a boundary-spanning, multi-purpose, and future-oriented vehicle for designing, planning, and realizing a business [ZAM11]. In the technological field, Chesbrough and Rosenbloom [CR02] define a business model as "*the heuristic logic that connects technical potential with the realization of economic value*". Thus, technological development is in tight interaction with strategic development.

5.3 State of the Art on Business Models

5.3.1 Visual Tools and Templates for Business Models

One classical example of visual tools and templates for business models is the Business Model Canvas (BMC) [Ost04]. The BMC is a visual chart used for developing and documenting the main activities of a business, to align the different components of a business and illustrate its potential trade-offs. The traditional BMC holds nine areas to explore: customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure.

The common aspect of these tools is the vision of exploring business opportunities and defining those processes that capture value through competitive advantages [CHE10]. With time, additional aspects have been brought into the business modelling. Nowadays it is understood that sustainable business models require a long-term business vision, which includes the integration of economic, environmental and social values into the value proposition, as well as stakeholders´ engagement [Elk94], [APD+22].

In a more interconnected world, markets can be better explained by the business ecosystem concept and stakeholder analyses [Fre84] [Mat18] must be included in a sustainable business modelling [APD+22]. A business ecosystem consists of interdependent stakeholders that are both collaborating and competing to create and sustain new markets and products. Such ecosystems may rely on the technological leadership of one or two stakeholders which provide a platform that affects the investments and strategies of the other members. The value capture component of a business model must find an acceptable balance between profits for the technologically leading stakeholders and the other ecosystem members [TL17]. It is a challenge to design and plan business models optimally for two or more interdependent firms since the business model concept has the perspective of a single firm. Thus, the derivation of business models in an ecosystem with several stakeholders will be discussed below.

Latest business modelling tools include additional areas, especially related to social and environmental sustainability and the concept of ecosystem:

The Doughnut economic model [RAW17] is a visual framework for sustainable development stating that there is a "safe space", within which business can be conducted without harming people, or the planet. The outer boundary is the environment, and the inner boundary is the society.

- The Sustainable Business Canvas [SBC20]: It adds to the traditional nine areas of the BMC two additional ones, namely eco-social costs and eco-social benefits.
- Circular Business Model [OECD18] [Sit22] includes a circular design perspective, describing the value capturing for customers, key partnerships, resources, and distribution models, explicitly including both social and environmental issues as outcomes.
- Flourishing Business Canvas [FBC]]adds to the classical nine areas of the BMC the dimensions of environment and society with a total of 17 areas to explore. It defines environment, society and economy areas as overlapping, in line with the Doughnut economic model.
- Ecosystem Pie [EP] focuses on describing the stakeholders of an ecosystem from the perspective of their value.
- The Rainforest Canvas [RC] allows for the visualisation of the innovation ecosystem of a company or product by describing stakeholders, leaders, resources, activities, engagement, role models, frameworks, infrastructure/capability/community and culture.

5.3.2 Business Models for Mobile Communications

Although business models in telecoms have been evolving since 2G, in order to create a canvas that makes sense for 6G, the business models related to 5G which involve a higher level of complexity [AAA+23], [BMM22] will be analysed and explored.

The General Bit-Pipe Mobile Network Operator (MNO) business model is the evolution of the current mobile operator, which offers mobile connectivity to users through mobile communication technologies (2G to 5G) in a mass-production or bit-pipe mode.

- The Segmented Specialized Service MNO business model offers mobile connectivity bundled with specialized content to selected segments, nationwide or regionally. These operators compete where the general bit-pipe operators are less competitive serving smaller niches to satisfy the long tail of customers through higher value-added services. Examples include smart learning environments, e-health, smart transportation, etc.
- The Wholesale Service Local Operator business model offers locally hosted connectivity to MNOs' customers as a neutral entity (i.e., neutral host). This typically happens in public places, such as campuses, hospitals, airports, cities, etc., where it is not economically feasible for all MNOs to build their network, but they can outsource it from a single local neutral operator.
- The Retail Service Local Operator business model offers local connectivity and complementary data services to end users in different private venues such as shopping centres, hotels, or workplaces in an independent fashion. In this business model, MNOs can provide private local connectivity to end-users, integrating the local network with the public one.
- The Vertical Service Local Operator business model offers private local network connectivity and related content and context services for verticals like factories, agriculture, electric grids, railways, and ports. This business model may serve both human and non-human (i.e., machine) demands.
- The Context Service Local Operator business model offers private local connectivity to provide personalized consumer services based on content and context data through, e.g., network slicing technology.

In general, 5G has enabled new business models for MNOs and new types of stakeholders in the ecosystem. Continuing this evolution, 6G is forecasted to hold even more stakeholders in the ecosystem. The following business models for 6G have been envisioned [AAA+23]:

The 6G MNO business model is the evolution of the 5G bit-pipe MNO, which offers an E2E value controlled by the MNO and supported by specialized firms connected to the connectivity platform of the 6G MNO. This model aims at matching user needs with the connectivity platform resources through, e.g., an automated network slicing to offer differentiated services to different user groups, both consumers and institutions, such as critical infrastructure providers.

- The OTT (over-the-top) operator business model offers content to the end users, by bypassing the traditional MNO's network, acting as a platform based on its cloud resources, leveraging connectivity from other traditional operators (e.g., bit pipes) to benefit from its large customer base. In this model, data and algorithms play a central role, as such business model focuses on human users and are envisioned to be the consumer or enterprise metaverse providers.
- The edge operator business model provides tailored localized connectivity, content, computing (i.e., hardware), and context services in one or multiple locations. Edge operators can be seen as the evolution of vertical service local or context service local operators of 5G who can specialize in serving customers at the edge, with a more advanced context-specific offer by matching customer needs through available data (shared within the ecosystem), which is processed at the edge of the network. Edge operators manage hyper-local cloud infrastructure services with scalability, required availability, and high flexibility.
- The telco broker business model offers connectivity or any other resource or asset needed for providing future mobile services. It emerges from the need for additional disruptors, complementors, and specialized service providers in the future 6G multi-platform ecosystem, being its role to match differing needs and resources. Examples of emerging needs are specialized data, artificial intelligence, and interface-control-based services, where a telco broker acts as a service enabler.

5.4 Methodology

Based on reviewing of existing business modelling approaches and ongoing 6G developments, the Hexa-X-II project has derived a new ecosystem-level business modelling approach that is applicable to use case-specific business modelling. The methodology consists of three steps for the use case: *ecosystem business model canvas* (ecosystem level business model for the use case including identification of stakeholders), *stakeholder analysis* (analysis of key stakeholders) and *ecosystem pie* (ecosystem level business model visualization).

Ecosystem Business Model Canvas

The first step of use case-specific business modelling is to develop a generic ecosystem-level business model for the use case. The ecosystem-level business model consists of elements that are derived from existing business model templates and brought together. The developed ecosystem-level business model canvas is illustrated in Figure 5-1 and consists of the following four main elements:

Ecosystem value propositions

- **Value proposition**: intended value arising from a customer-oriented solution characterized by a system level goal [TWP+20].
- **Value co-creations:** what value is co-created in the ecosystem between the stakeholders satisfying their needs while depending on each other but do not controlling each other [FBC].
- **Value capture:** how, what kind and how much value created by the ecosystem is captured through different means including direct financial gains, growth, reputation, higher efficiency, etc. [TWP+20].
- **Value co-destructions:** what value is destroyed, what are the obstacles for creating value and what hinders the realization of the use case [FBC].
- **Partnerships:** governing of the ecosystem partners through formal partnership agreements, contracts, norms, regulations and institutional arrangements [FBC].

Supply side

- **Stakeholders/key partners**: who affect or are affected [Fre84] by the use case on the supply side.
- **Resources (incl. environmental and social):** key tangible and non-tangible resources [FBC] including assets, skills, capabilities, etc. needed for value creation [TWP+20].
- **Activities:** mechanisms to generate productive contributions to the ecosystem [TWP+20].

Demand side

- **Customer segments**: end users, subscribers, beneficiaries and other target markets [TWP+20] for the value created in the ecosystem.
- **Stakeholders/key partners**: who affect or are affected [Fre84] by the use case on the demand side.
- **Customer relationships**: type of relations to build with the customers [SBC20].
- **Channels:** communication and form of interaction with customers and delivery of the services/products in all phases of the business cycle [SBC20].

Outcomes

- **Benefits (incl. benefits to environmental, social and economic aspects):** positive aspects from the business [SBC20] [FBC].
- **Revenues (revenue streams):** where, how and how much revenues come from the value proposition [SBC20].
- **Pricing:** ways of pricing the products and services and charging for the use in terms of what they pay for and how [SBC20]
- **Costs (incl. costs to environmental, social and economic aspects):** different costs that need to be supported in delivering the value proposition [SBC20] [FBC].

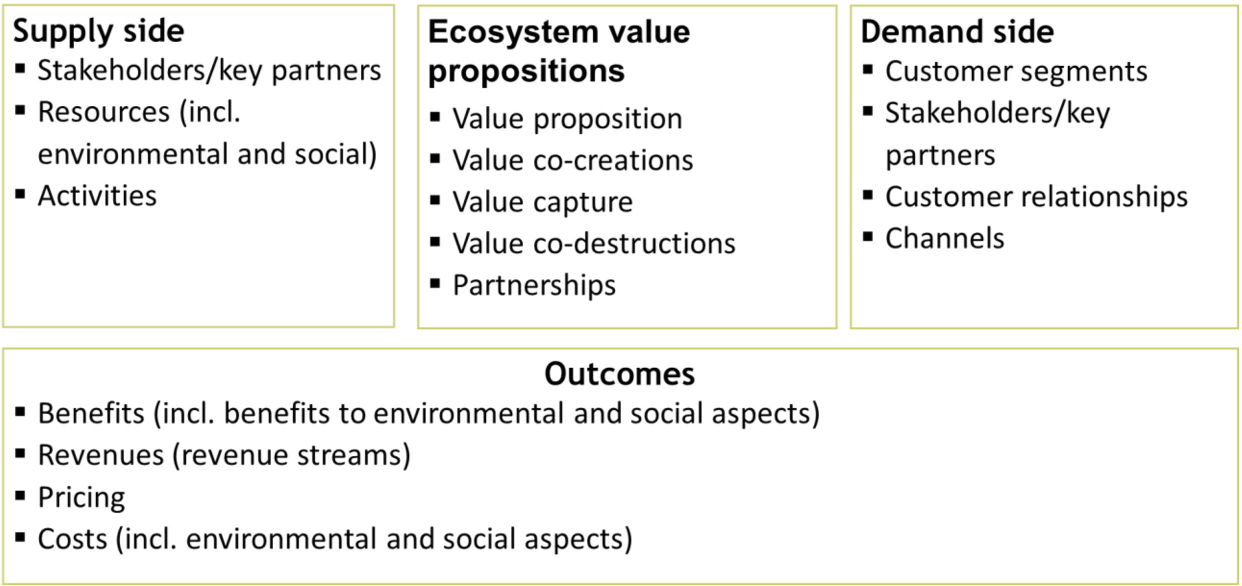

Figure 5-1: Hexa-X-II Ecosystem Business Model Canvas.

Stakeholder Analysis

The second step in the developed business modelling methodology is stakeholder analysis where the key stakeholders for the use case are identified and described. Stakeholder analysis starts by identifying stakeholders relevant to the use case and selecting the key stakeholders for more detailed analysis. The key stakeholders are then analysed for their role in the use case, value proposition, activities and resources, and presented in a table for further analysis. This analysis takes the ecosystem-level business canvas deeper to the stakeholder level by identifying the value proposition, activities and resources at the stakeholder level.

Ecosystem Pie

The third step in the business modelling is to visualize the ecosystem business model using ecosystem pie for the use case by showing the ecosystem consisting of the key stakeholders. The ecosystem pie consists of the ecosystem's value proposition and key stakeholders' roles, value propositions, activities and resources as an onion figure where sectors present the different stakeholders and the rings present the different elements of stakeholder analysis, see Figure 5-2.

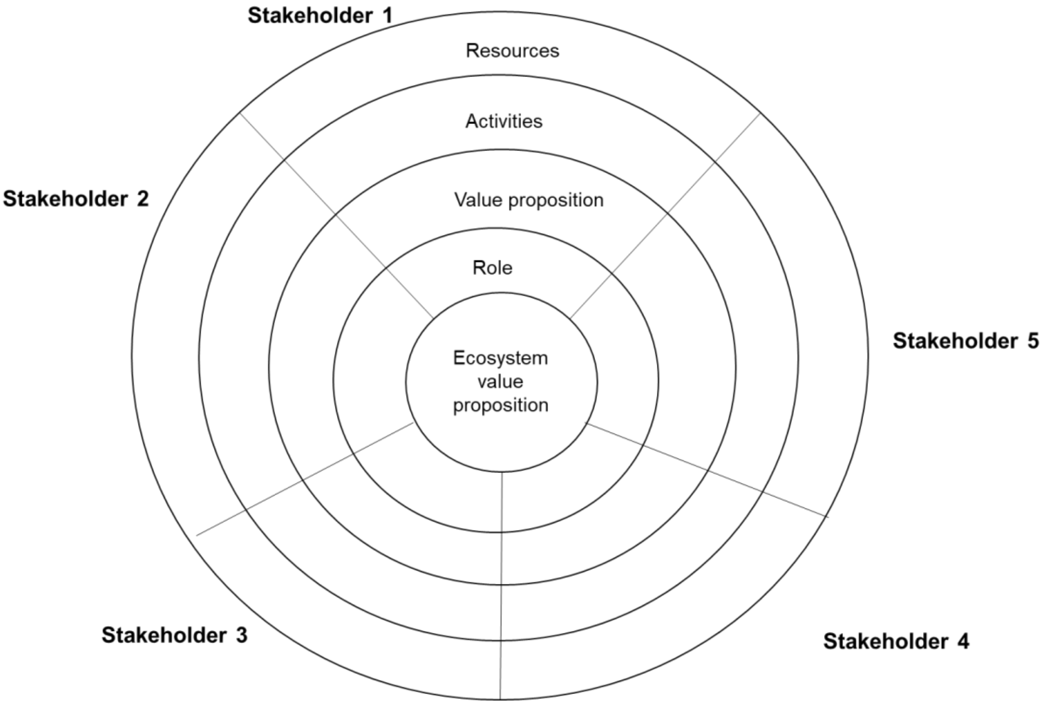

Figure 5-2: Hexa-X-II Ecosystem Pie

5.5 Developed Initial Business Models for Selected Representative Use Cases

Next, the developed methodology for business modelling presented in Section 5.4 is applied to three selected representative use cases. These representative use cases include Seamless Immersive Reality, Realtime Digital Twins and Ubiquitous Network. The use cases were selected to investigate different types of use cases resulting in different business offerings and ecosystems around the use cases. Seamless Immersive Reality represents local usage that brings together participants from different locations to co-create value. Realtime Digital Twins expand the use of 6G to make use of digital replicas of complex systems to optimize operations in real-time in a multi-stakeholder ecosystem leading to potential cost savings. Finally, the Ubiquitous Network representative use case aims at providing connectivity to all, which forms the foundation for businesses making use of the connectivity.

5.5.1 Seamless Immersive Reality

The business model developed for the Seamless Immersive Reality use case is shown in Table 5-1, Table 5-2, and Figure 5-3. The ecosystem business model canvas in Table 5-1 summarizes ecosystem value propositions, supply and demand side descriptions and outcomes. The overall value proposition of the Seamless Immersive Reality use case is to offer "an *enhanced ability to get a shared understanding of an interaction with multi-dimensional and/or textual objects/topics/people with increased output quality of interaction*". The key identified stakeholders include providers of equipment for seamless reality technologies, providers for seamless experience applications, telecom infrastructure providers, network operator/service providers, and other end users, which are detailed in Table 5-2 Finally, the ecosystem pie visualization is shown in Figure 5-3 presenting the ecosystem's value proposition and key stakeholders' roles.

<table>
<tr><th>Supply Side</th><th>Ecosystem Value Propositions</th><th>Demand Side</th></tr>
<tr><td>Stakeholders/key partners: Providers of equipment of seamless reality technologies; Providers of seamless experience applications (including content and marketplace for services); Telecom infrastructure providers (network vendor); Network operator/service provider; Other end users.
Resources: Internet of senses; devices; compute resources; AI algorithms; data and access to data; domain specific competence; communication network (can be local private network); funding; design processes; IPR.
Activities: Design and develop seamless experience and applications; capturing content; deploying suitable network; traditional operations.</td><td>Value proposition: Enhanced ability to get a shared understanding of an interaction with multi-dimensional and/or textual objects/topics/people with increased output quality of interaction.
Value co-creations: Enhanced mutual interactions with people far away (telepresence) and co-experience for increased common understandings; improved quality of experience (QoE) facilitating interaction, collaboration, co-presence, and co-experience in many aspects of life including work, education, or healthcare, and cultural, social, and personal lives. Marketplace for services (commerce in the virtual world).
Value capture: users, or those wanting immersive reality to be applied, will capture value; in turn, others take advantage of increased quality such as patients, employers, customers of manufactured components, and art consumers).
Value co-destruction: Competition for owning end-user/customer relationship; timing in launches by different stakeholders; non-compatibility limits interaction; role of advertisements
Partnerships: Providers of connectivity, Immersive reality equipment, Content, SW.</td><td>Customer segments: consumer; employer/institution (industry, architects, health, education) - for end-users; game/immersive reality publisher; immersive reality equipment providers.
Stakeholders/key partners: End users; Subscriber of the service (who pays); Customer relationships: Business to Consumer/user; Business to Business user; Business to User equipment provider to Consumer.
Channels: Digital channels; Direct sale; distributors; partner distributors; tenders.</td></tr>
<tr><th colspan="3">Outcomes</th></tr>
<tr><td colspan="3">Benefits: Efficiency and productivity improvements; fostering a healthy social life (inclusion; the pleasure of social interaction, and well-being); allowing for new ways of working; enhancements to innovation; carbon footprint reductions.
Revenues (revenue streams): Alternative streams: customers can buy bundles of equipment/connectivity/services, or direct to all providers. Examples: Payments from user/customer to operator; Payments from employer/institution to operator (of private network - wide area network); Payments from employer to equipment provider to operator; Payments from employer to equipment provider AND operator AND content provider.
Pricing: Different models: subscriptions per end-user/user equipment; wholesale prices, per subscription or per volume level (e.g., game publishers or equipment providers who bundle connectivity into service); as-much/many UEs-as-you-can-eat limited by geography; time.
Costs: High costs for general support for immersive reality; requirements for ubiquitous QoS in the intended coverage area and the reality of lower and unpredictable QoS in wide area network; growth of immersive reality in socially not-so-acceptable or illegal domains; unintended growth of digital storage and resource usage (waste).</td></tr>
</table>

Table 5-1: Seamless Immersive Reality Business Model Canvas

Stakeholder	Description	Role	Value proposition	Activities	Resources
Providers of equipment for seamless reality technologies	Providers for equipment of seamless reality	Supplier	Equipment which is easy to use and set up, to engage with content personal equipment, or easily shared with other people	Development, delivery and maintenance of equipment. Research, design, manufacturing (outsourced), sale/distribution	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise.
Providers of seamless experience applications (including content and marketplace for services)	Providers of applications and content for seamless experience	Supplier	Attractive and useful content that can be made available efficiently in a marketplace	Ideate, design, and build content. Share. Manage users, and potential purchasers of content creation and sharing. Sales and customer relationships.	Expertise. Processes. Skills and tools. Capital. Brand.
Telecom infrastructure providers (network vendor)	Vendor of communication network infrastructure, which has sensing capability.	Supplier	Robust and predictable general-purpose large-scale sensoring equipment and make available trustworthy monitoring data.	Research, design, manufacturing (outsourced), sale/distribution,	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise. Scaling capabilities.
Network operator/ service provider	Provider of local/wide area connectivity services supporting immersive experience.	Supplier	Investment and costs in the network can be justified by the use and users, and what they pay for deploying and running the network. For business modelling: a need to identify more uses for private networks to make a business case	Operate local network. Handle relationship with network owner/financer - and users, access rights of the network.	Local active (and passive network). Human operation and support. Financial resources. Spectrum ownership. Installed network (infrastructure and people). Knowledge about network sourcing and deployment. Customer base.
End users	students, teachers, common people	Customer	Perceived value for price: inclusion, social interaction, well-being and being entertained; productivity, innovation, quality, motivation. Reduced carbon footprint. Test before purchase.	Use the immersive reality services. Potentially pay for services for an immersive experience. Require support.	Acquired equipment and applications to use the services. Sufficient financial resources. Rented devices (rental model for sharing and limiting device proliferation).
Subscriber of the service (who pays)	Financing actor/sponsor of content/applications/ connectivity, e.g., education	Customer	Perceived value for price: Productivity, innovation, quality, motivation, better use of scarce human resources, inclusion, reduced carbon footprint, test before deployment (product, medicine…).	Pay for services for immersive experience, on behalf of users	Sufficient financial resources, and mechanisms which enables to assess, prioritize, and purchase "new" tools (pioneer)
Other end users	other end users to use the seamless experience with	Supplier	Being available for other end users who would want to reach to create critical mass	Use the immersive reality services.	Acquired equipment and applications to use the services.

Table 5-2: Seamless Immersive Reality Stakeholder Analysis

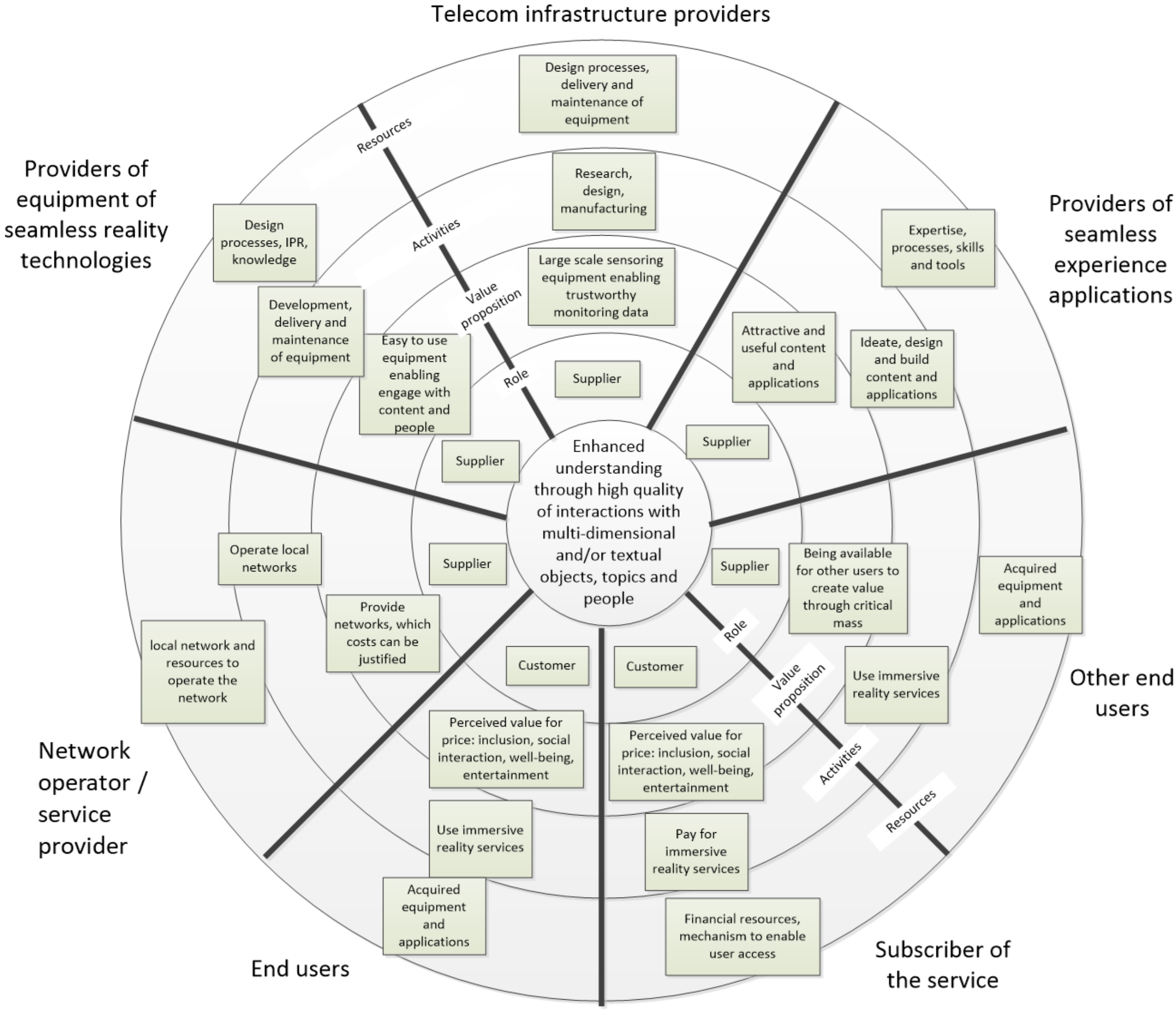

Figure 5-3: Seamless Immersive Reality Ecosystem Pie

5.5.2 Realtime Digital Twins

The business model developed for the Realtime Digital Twins use case is shown in Table 5-3, Table 5-4, and Figure 5-4. The ecosystem business model canvas in Table 5-3 summarizes ecosystem value propositions, supply and demand side descriptions and outcomes. The overall value proposition of the Realtime Digital Twins use case is to offer "new business opportunities and increased efficiency from multiple stakeholders meeting in a virtual digital twin being immersed and bringing together capabilities to co-create value by solving challenges remotely and collaboratively". Key identified stakeholders include sensor providers, digital twin providers, telecom infrastructure providers, network operator/service providers, end user equipment providers, providers of components that need to be digital twinned, providers/integrators of applications on top of the digital twin, which are detailed in Table 5-4. Finally, the ecosystem pie visualization is shown in Figure 5-4 presenting the ecosystem's value proposition and key stakeholders' roles.

Supply Side

- **Stakeholders/key partners:** Sensor providers; Digital twin providers; Telecom infrastructure providers; Network operator/service provider; End-user equipment providers; Providers of components that need to be digital twinned; Providers/integrators of applications on top of the digital twin
- **Resources:** IoT devices; robots; compute resources; AI algorithms; data and access to data; digital twin data; domain specific competence; communication network; funding; buildings; infrastructure; natural resources and raw materials; Design processes; IPR; Factories Workforce;
- **Activities:** Coordination and cooperation between stakeholders; development of twin/replication of a large entity for interactions; providing connectivity; R&D; design; manufacturing; deployment; sales; operation maintenance; circular business; sustainability management; life cycle management; ethical management; authentication

Ecosystem Value Propositions

- **Value proposition:** New business opportunities and increased efficiency from multiple stakeholders meeting in a virtual digital twin being immersed and bringing together capabilities to co-create value by solving challenges remotely and collaboratively.
- **Value co-creations:** Increased efficiency of stakeholders' operations by multiple stakeholders meeting in digital twins through automation, remote monitoring and handling of infrastructure allowing better information sharing and coordination of stakeholders' processes in the value chain and common system development and changing the ways of working/collaboration through better coordination (example: industrial metaverse).
- **Value capture:** Those in control of processes can extract value from the use of digital twins to optimize the processes.
- **Value co-destruction:** Complex collaboration contracts; Risk of not being able to create a full digital twin (getting data from all involved stakeholders); need for standardization to allow digital twins to collaborate and exchange information.
- **Partnerships**: Relation between the digital twin provider and the user of the digital twin (can be different models: as a service (aaS)).

Demand Side

- **Customer segments:** Building/site/facility owners/operators
- **Stakeholders/key partners:** Building/site/facility owners/operators; Owner of the digital twin; Humans/real users (humans using digital twin in the site and those being monitored);
- **Customer relationships:** Business to owner of digital twin (money flow); Business to the users of digital twin (customer support)
- **Channels:** Tenders; direct sale;

Outcomes

- **Benefits:** Resource savings (including materials, energy); reduced waste; reuse of materials over product/construction cycles; safety improvements; reduced costs; reduced burden on environment (achieving sustainability targets); making the world more manageable 24/7; reduced dependency on human resources and burden on humans doing things right; better overview of what resources are used - a system to manage circularity; new jobs for new competences; making use of digital twin for the network in the location (network management); using of digital twin before constructs are finished for training/preparing before opening; better working environment for the person/worker.
- **Revenues (revenue streams):** Different financing/charging models for the use of digital twin (as a service-monthly fees; invest yourself; different stakeholders to invest to provide revenues for digital twin providers); reduced costs; multiple use cases needed to justify the cost.
- **Pricing:** Different models: everything aaS from one stakeholder; buying/doing yourself the sensors/analysis/digital twin; subscriptions for devices & services (incl. connectivity); aggregation of subscriptions.
- Costs: More dependency on specific skills/systems; costs of training of workers; costs of creating and maintaining digital twin; footprint from devices; cost of exposing critical information about infrastructure and operations.

Table 5-3: Realtime Digital Twins Business Model Canvas

Stakeholder	Description	Role	Value proposition	Activities	Resources
Sensor providers	Providers of sensors of different types	Supplier	Robust and predictable installations of need-specific sensors.	Development, delivery and maintenance of sensors. Sales and customer relationships. Logistics. Inventory services.	Design processes. IPR, knowledge, experts. Scaling capabilities. Logistics and preconfiguration capabilities/systems/processes.
Digital twin providers	Provider of digital twin including digital twin applications SW and HW.	Supplier	To offer a digital twin tool/service, which benefits stakeholders/users in their daily work.	Design, creation and maintenance of digital twin application and HW. Management of use and access. Sales and customer relationships. Authentication.	IPR and copyright, experts, vertical domain knowledge.
Telecom infrastructure providers (network vendor)	Vendor of communication network infrastructure, which has sensing capability.	Supplier	Robust communication network infrastructure which allows stakeholders to use and develop the digital twin. Robust and predictable general purpose large scale sensing equipment, and make available trustworthy monitoring data.	Research, design, manufacturing (outsourced), sale/distribution,	Design processes. IPR, knowledge. People. Own factories - or outsourcing expertise. Scaling capabilities.
Network operator/ service provider	Provider of the connectivity service supporting digital twinning, especially for the local area of twinning. Can be public network or local private network.	Supplier	Investment and costs in the network can be justified by the use and users, and what they pay for deploying and running the network. For business modelling: a need to identify more uses for private networks to make a business case	Operate local network. Handle relationship with network owner/financer - and users, access rights of the network. Authentication.	Local active (and passive network). Human operation and support.
End user equipment providers	Provider of equipment that end users use to access the digital twin.	Supplier	Easily connect users of digital twin applications, new and for the first time.	Design, develop, operate application/ functionality/equipment. Manage IDs and users, privacy regime. Sell and promote.	Algorithms. Applications (code). IPR. Experts.
Providers of components that need to be digitally twinned	(e.g., machines in factory);	Supplier	Easy integration of devices into digital twin environment; easy replicability	Research, design, manufacturing, sale/distribution,	IPR; data generated by the components
Building/site/facility owners/operators	Owners/operators of buildings/sites/ facilities which are the core of the digital twin.	Customer	Efficiency in processes for people and the environment	Operate the facility	Physical facilities
Owner of the digital twin	Owner of the digital twin	Customer	Efficiency in processes for people and the environment	Make use of the digital twin. Optimize the operation of the facility	Digital representation of the facility
Provider/integrator of applications on top of the digital twin	Provider of applications that make use of the digital twin or integrate to the digital twin	Supplier	To extend the digital twin beyond what the digital twin provider can do itself	Design, creation and maintenance of applications on top of digital twin Sales and customer relationships.	IPR and copyright, experts, vertical domain knowledge.
humans/real users (humans using digital twin in the site+those being monitored);	Human users of the digital twin.	Customer	Perspectives on boundaries for general sensing services	Carry out normal and expected activity. Respond precautious and reactively to sensing environments. Give feedback.	Citizens. Employee. Right to be heard.

Table 5-4: Realtime Digital Twins Stakeholder Analysis

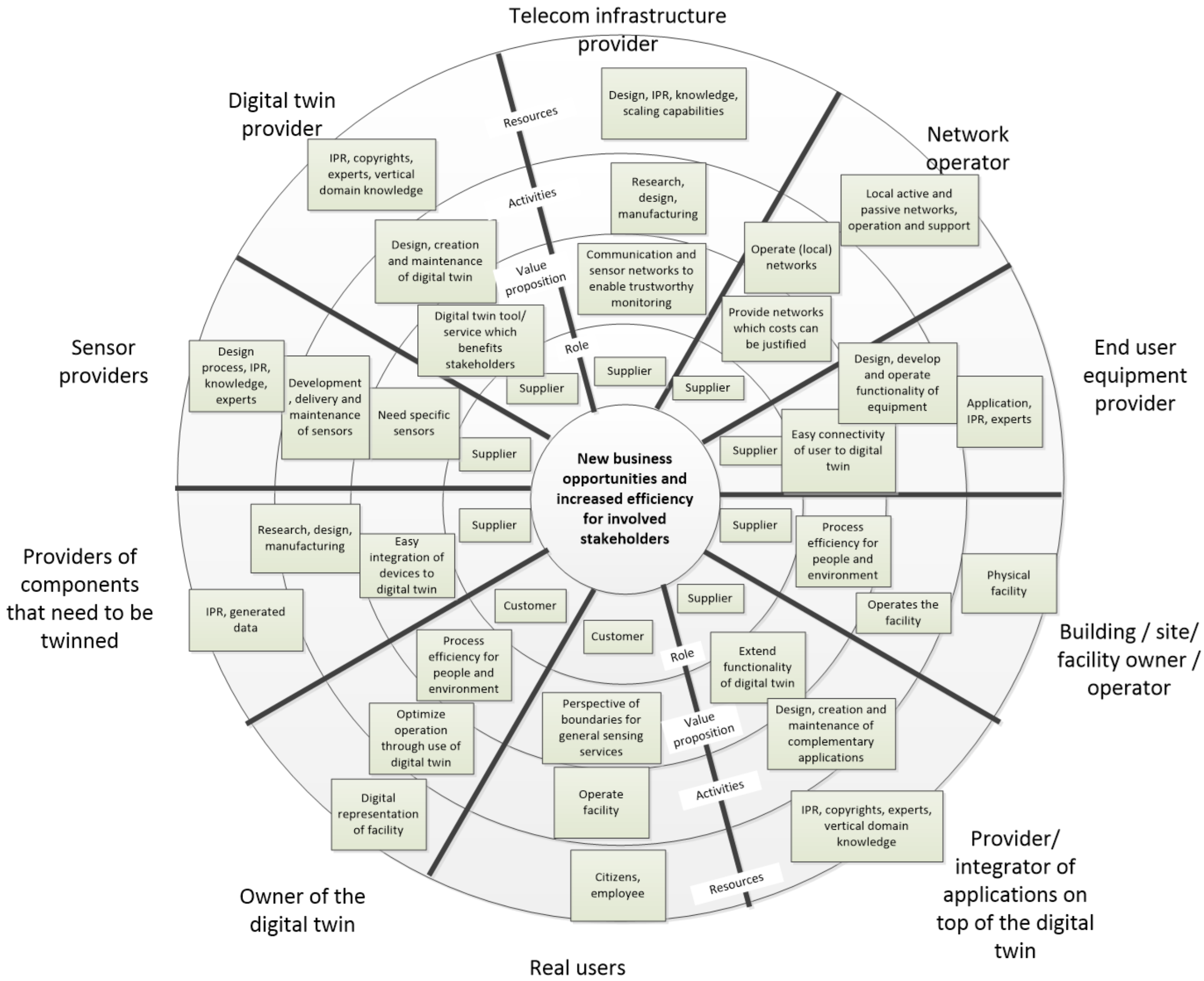

Figure 5-4: Realtime Digital Twins Ecosystem Pie

5.5.3 Ubiquitous Network

Finally, the third representative use case for business modelling, the Ubiquitous Network, is presented in Table 5-5, Table 5-6, and Figure 5-5. The ecosystem business model canvas of in Table 5-5 summarizes ecosystem value propositions, supply and demand side descriptions and outcomes. The overall value proposition of the Ubiquitous Network use case is "*Giving everyone, everywhere the possibility to access digital services. Global mobile broadband connectivity through reliable integration of multiple networks securing digital inclusion and privacy*". Key identified stakeholders include sensor infrastructure network providers, non-terrestrial network connectivity including Earth station providers, wide area network providers, local networks providers, providers of energy infrastructure, end users and subscribers, which are detailed in Table 5-6. Finally, the ecosystem pie visualization is shown in Figure 5-5, presenting the ecosystem's value proposition and key stakeholders' roles.

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Supply Side

- **Stakeholders/key partners:** Infrastructure NW provider; NTN including Earth station providers; Wide area network provider (CSP, ISP); Local networks provider (DSP) and small-scale base station operator/owner (radio resource); Provider of energy infrastructure; Planet Earth and Future Generations
- **Resources:** Design processes; IPR; Factories; TN & NTN infrastructure; Raw materials; Water; Workforce; Energy; Collaborative funding
- **Activities**: Research, Development ; Design; Manufacturing; Deployment; Sales; Operation Maintenance; Circular business; Sustainability Management; Life cycle management; Ethical management

</td>
<td>

Ecosystem Value Propositions

- **Value proposition:**: Giving everyone, everywhere the possibility to access digital services. Global mobile broadband connectivity through reliable integration of multiple networks securing digital inclusion and privacy
- **Value co-creations:** Examples: Suppliers: re-use of infrastructure and collaboration reduce costs for R&D. Customer and Supplier: Sharing of customer data can be used to improve services. Enhanced knowledge in the workforce. Co-funding of investments.
- **Value capture**: More customers when global connectivity (but probably many customers with low income), higher efficiency, shared investments, new business opportunities
- **Value co-destruction**: Complex collaboration contracts; Exploitation of commons; Unintended Reduced Fundamental Freedoms
- **Partnerships**: Partnerships needed for covering the unconnected but also to expand services given, i.e. payments; education; and health services based on local needs and legislation

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Demand Side

- **Customer segments**: end-user; subscriber
- **Stakeholders/key partners:** end-user; authorities; private companies; governments; Non-Governmental Organizations (NGOs); Planet Earth and Future Generations; Workforce
- **Customer relationships**: B2B and B2C and B2B2C
- **Channels**: Word of mouth (trusted); Social media; Government/Authority channels; Feedback channels from stakeholders

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Outcomes

- **Benefits (incl. benefits to environmental and social):** digital inclusion; reuse of resources; faster distribution of information and new ideas; increased competition; facilitated market transactions; environmental monitoring; reduced GHG emissions if more services can be accessed without travelling; enhanced trustworthiness of networks
- **Revenues (revenue streams):** Fixed yearly fee per government, private companies, and NGOs giving basic service. Additional fee for end-users based on usage.
- **Pricing**: Differentiated pricing for countries based on GDP and purchasing power among individuals
- **Costs (incl. costs to environmental and social)**: Shared infrastructure investments and cost to create interfaces between networks; higher energy and maintenance costs; GHG emissions; Waste handling; Imposed monitoring; Increased land use could cause biodiversity loss; Higher energy usage; Potential digital divide if all services digital

</td>
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</table>

Table 5-5: Ubiquitous Network Business Model Canvas

Stakeholder	Description	Role	Value proposition	Activities	Resources
Infrastructure equipment provider	Provider of the HW necessary to set up a network	Supplier	Extended market geographically and technically gives new opportunities and ways of sharing R&D investments	R&D, design & manufacturing of infrastructure and providing network services	Competence; design processes, IPR, factories
Non-Terrestrial-Network-Connectivity incl. Earth station	NTN provider has the satellites, and signals must be captured/sent via an earth station to TN	Supplier	Connecting the unconnected when NTN and TN are combined	R&D, deployment, operation, maintenance of NTN incl. earth stations	NTN and earth stations; expertise; frequencies
Wide area network provider (CSP, ISP)	Provides connectivity (the CSP role) in wider areas, via the Internet (the ISP role)	Supplier	Mobilize total market, cost and energy reduction/efficiency. Resource sharing/optimization.	Deploy and operate networks. Sell, onboard-support-offboard users/customers.	Installed/controlled network (infrastructure, spectrum, customers and people). Knowledge about network sourcing and deployment.
Local networks provider (DSP). Local, small-scale base station operator/owner (radio resource)	Provides connectivity in very local areas. Layer 2, plus 3. Can be more networks using the same radio.	Supplier	Enable local community inclusion, or other stakeholders to finance local radio coverage.	Operate active local network infrastructure. Handle interconnectivity and roaming agreements.	Installed/controlled local network (infrastructure, spectrum, customers and people) used within geographical area of radio. Knowledge about network sourcing and deployment.
Provider of energy infrastructure	Power companies	Supplier	Enable operation of network services by providing energy	Power generation preferably through renewable sources	Energy infrastructure, permits to operate, capital to invest
End-user	The person who is receiving services, at a geographically specific place	Customer	Access to trustworthy basic citizen services (UE, network, application), reliable in private events of high importance.	Use services: login, use, share with others,	Skill, time, motivation, perceived benefits, give feedback to suppliers.
Subscriber (governments, authorities, NGOs, private companies)	The entity which is paying for realizing a service. Many B2B2B2C configurations.	Customer	Finance local networks to secure the availability of basic citizen digital services to everyone.	Use decision rights, and controlling mechanisms as legislation to direct investments. Sign up for subscription to services.	Ability to pay, policy decision rights over some resources, give feedback to suppliers.

Table 5-6: Ubiquitous Network Stakeholder Analysis

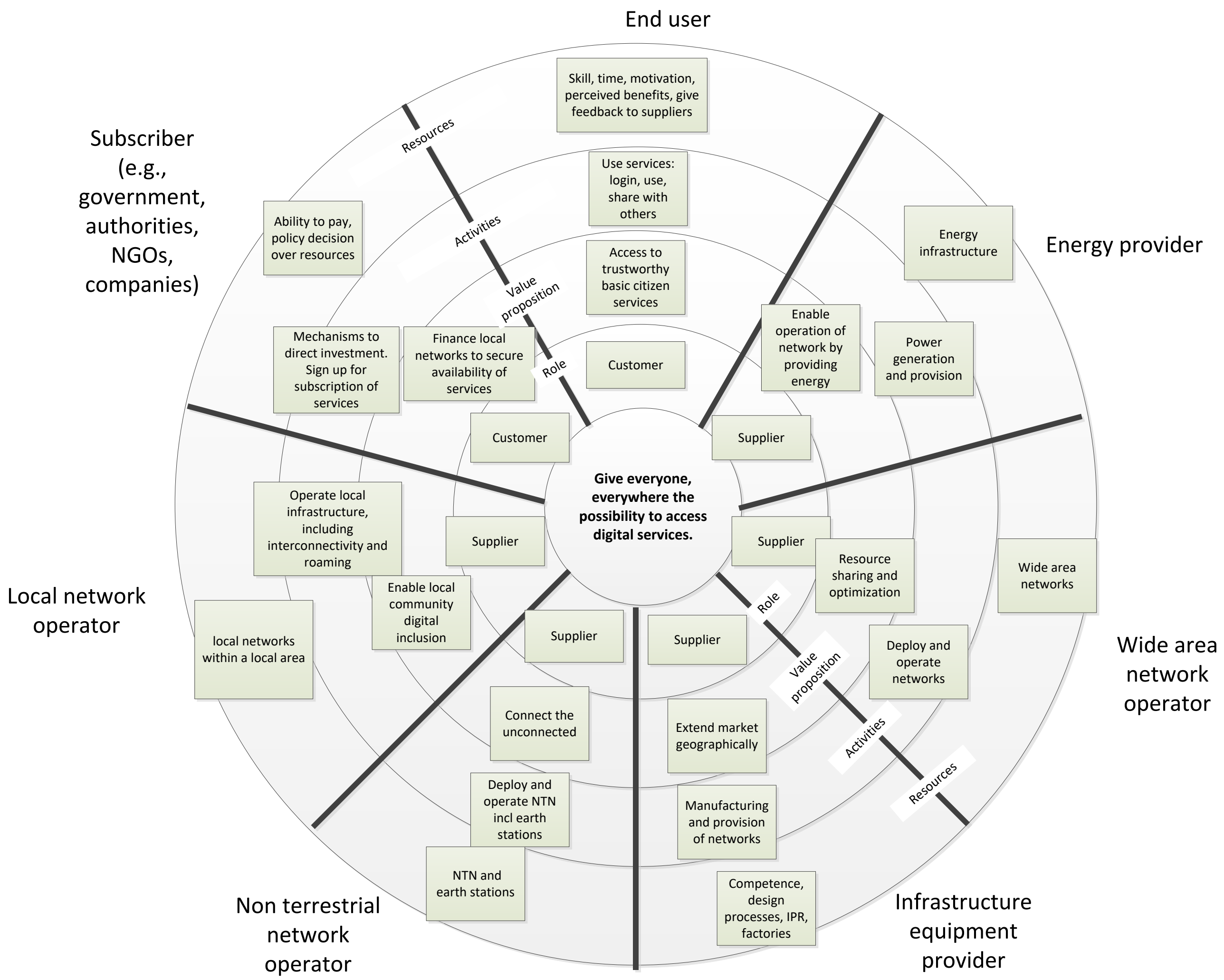

Figure 5-5: Ubiquitous Network Ecosystem Pie

5.6 Business Models Summary

Hexa-X-II has developed a new ecosystem-level business modelling approach to further explore the business aspects of the developed representative use cases building on state-of-the-art business models. The developed business modelling methodology consists of three steps: ecosystem business model canvas, stakeholder analysis, and ecosystem pie visualization. The Hexa-X-II ecosystem business modelling approach has been applied to three selected Hexa-X-II representative use cases derived in Section 3 to give first insights into the value propositions, demand and supply sides and outcomes of the selected use cases.

The initial business models derived for the three representative use cases showcase the ecosystem's value proposition and describe the key stakeholders needed to realize the use case and deliver value. Distinct sets of value propositions, key stakeholders and outcomes were identified in the use cases highlighting the potential emergence of different ecosystems around the use cases with different resource configurations. Seamless Immersive Reality offers enhanced understanding through high-quality interactions with multi-dimensional and/or textual objects, topics and people as value propositions. Realtime Digital Twins use case offers new business opportunities and increased efficiency for involved stakeholders as a value proposition. Ubiquitous Network offers everyone everywhere the possibility to access digital services as a value proposition. These three representative use cases are expected to be realized with different ecosystems and stakeholders highlighting different activities and roles. Different benefits were observed ranging from efficiency and productivity improvements and resource savings to digital inclusion. The developed Hexa-X-II business modelling approach serves as a tool to analyse the business aspects of 6G use cases at the ecosystem level.

6 Conclusions

This deliverable presents six 6G use case families and six representative use cases, compiled in Hexa-X-II. They represent an evolution from an initial set of use cases presented in June 2023 in D1.1. The deliverable also reflects how different European partners consider that the needs of society in 2030 will affect 6G use cases. The partners in Hexa-X-II believe in a combination of new and exciting technological features such as *sensing, digital twins,* or *AI/ML capabilities*. Additionally, the 6G use cases aim to enhance existing 5G scenarios with requirements and KPIs currently unattainable by 5G, such as *Immersive Reality, Cooperating Mobile Robots,* and *Trusted Environments*.

From each use case family, one use case has been selected to represent key aspects of that family. These six representative use cases are analysed to extract the requirements and KPIs that will guide the research in the subsequent Hexa-X-II project stages (e.g., the designing phase). While being inspired by the capabilities introduced in the IMT2030 Framework, the KPI analysis emphasizes E2E performance aspects. Accordingly, further refinement of capabilities and iterations with the Hexa-X-II design phase are expected before definitive KPI values can be finally suggested.

A comparison of Hexa-X-II use cases with other 6G use case initiatives around the globe shows a shared comprehension of key technologies in the development of the 6G era. There is consensus about expanding current 5G capabilities (uRLLC, eMBB, MTC) to advance beyond them by including AI/ML capabilities and sensing, conceiving interoperability with NTNs, and evolving novel applications such as DTs and XR services.

However, unlike the other initiatives assessed, Hexa-X-II has expanded beyond only sustainable energy efficiency. Hexa-X-II has taken a concrete and transparent step to include environmental, social, and economic sustainability as key elements of the detailed analyses for all representative use cases. The inclusion of the three pillars of sustainability is vital in light of the expected ubiquity of the 6G ecosystem, highlighting the importance of designing a value-oriented ecosystem. Thus, Hexa-X-II strongly believes that all 6G use cases should be addressed through the sustainability lens and that considering only 50% of use cases with a sustainability impact is not sufficient. The deep dive will be further expanded in Deliverable D1.3, including sustainability assessment, risks, and mitigation strategies.

In the process of designing a new technology, the analysis of the spectrum and the existing channel models have revealed that most current frequencies and existing channel models are applicable to the analysed use cases. However, there might be a specific need for additional spectrum in use cases such as *Seamless Immersive Reality* or *Realtime Digital Twins*. Also, a new technology capability such as sensing introduces a new paradigm in the radio aspect, requiring the development of new channel models.

Eventually, the realization of 6G use cases requires business models. However, in a 6G ecosystem oriented on sustainability values, business models go beyond ’revenue as a goal’. To conceive the sustainability-oriented 6G ecosystem, values in many dimensions must be created and captured for many stakeholders, as well as specific business opportunities for single stakeholders. To do so, the project has developed and applied a novel ecosystem-level business modelling approach, and has applied it to three representative use cases. These use cases (*Seamless Immersive Reality, Realtime Digital Twins,* and *Ubiquitous Network*) represent a game changer from a user’s perspective compared to former generations. Also, different benefits were observed ranging from efficiency and productivity improvements, resource savings, and digital inclusion. These analyses and modelling will be continued and further enhanced in D1.3.

7 References

[22.104] 3GPP, "TS 22.104: Service requirements for cyber-physical control applications in vertical domains", Rel-19 v19.1.0, September 2023

[25.996] 3GPP TR 25.996, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations", Rel-17 v17.0.0.0, April 2022

[36.873] 3GPP TR 36.873, "Study on 3D channel model for LTE", Rel-12 v12.7.0, January 2005

[38.101] 3GPP TS 38.101-1, "User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone (Release 18)", Rel-18 v18.3.0, September 2023.

[38.855] 3GPP TR 38.855 "Study on NR positioning support", Rel 16 v16.0.0., March 2019

[38.901] 3GPP TR 38.901, "Study on channel model for frequencies from 0.5 to 100 GHz", Rel-17 v17.0.0, March 2022

[6GB] 6G Bridge, "6G Bridge - Business Finland" https://www.businessfinland.fi/en/for-finnish-customers/services/programs/6g-bridge, [Accessed by: December 2023]

[6GF] *6G Forum* "5G Forum" http://www.5gforum.org/html/en/main.php, [Accessed by: December 2023]

[6GFl] 6G Flagship "6G Flagship – More than wireless" https://www.6gflagship.com/, [Accessed by: December 2023]

[6GP] 6G Platform Germany "6G Platform – The german platform for future communication technologies and 6G (6g-platform.com)" https://www.6g-platform.com/, [Accessed by: December 2023]

[AAA+23] Ahokangas, P., Aagaard, A., Atkova, I., Yrjölä, S., & Matinmikko-Blue, M. Business Models in 5G/6G Mobile Communications. In *The Changing World of Mobile Communications: 5G, 6G and the Future of Digital Services*, Cham: Springer International Publishing, pp. 137-165, 2023.

[APD+22] Attanasio, G., Preghenella, N., De Toni, A. F., & Battistella, C. Stakeholder engagement in business models for sustainability: The stakeholder value flow model for sustainable development. *Business Strategy and the Environment*, *31*(3), 860-874, 2022

[B5P] Beyond 5G Promotion Consortium "Beyond 5G Promotion Consortium (b5g.jp)" https://b5g.jp/en/, [Accessed by: December 2023]

[B5P23] Beyond 5G Promotion Consortium "Message to the 2030s", March 2023 https://b5g.jp/doc/whitepaper_en_2-0.pdf

[B6G] Bharat 6G alliance "Bharat 6G Alliance" https://bharat6galliance.com/, [Accessed by: December 2023]

[B6G23] Bharat 6G Vision " https://bharat6galliance.com/img/Bharat-6G-Vision-Statement-copy%202_1.pdf", March 2023

[BMM22] Banda, L., Mzyece, M., & Mekuria, F. 5G business models for mobile network operators–a survey. *IEEE Access*, 2022.

[CHE10] Chesbrough, H. Business model innovation: Opportunities and barriers. Long Range Planning, 43(2–3), 354–363, 2010

[COST2100] Cost Action 2100 - Pervasive Mobile & Ambient Wireless Communications, https://www.cost.eu/actions/2100/, Dec 2010

[COST259] Cost Action 259 "Wireless flexible personalised communications", https://www.cost.eu/actions/259/, December 1999

[COST273] Cost Action 273 “Towards Mobile Broadband Multimedia Networks”, https://www.cost.eu/actions/273/, May 2005

[CR02] H. Chesbrough, R.S. Rosenbloom, The role of the business model in capturing value from innovation: Evidence from xerox corporation’s technology spin-off companies. Industrial and Corporate Change, 11(3), 529–555, 2002

[DDO+10] N. Dahan, J. Doh, J. Oetzel, & M. Yaziji. Corporate NGO collaboration: Co-creating new business models for developing markets. Long Range Planning, 43(2–3), 326–342, 2010

[DHK23] M. F. De Guzman, K. Haneda and P. Kyösti, “Measurement-based MIMO channel model at 140GHz (Version 1),” available: https://doi.org/10.5281/zenodo.7640353.

[DH23] M. F. De Guzman and K. Haneda, "Analysis of Wave-interacting Objects in Indoor and Outdoor Environments at 142 GHz," in IEEE Transactions on Antennas and Propagation.

[DKH22] M. F. De Guzman, P. Koivumäki and K. Haneda, "Double-directional Multipath Data at 140 GHz Derived from Measurement-based Ray-launcher," 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), Helsinki, Finland, 2022, pp. 1-6.

[ED26] Digital Spain 2026 “Home | España Digital 2026 (espanadigital.gob.es)” https://espanadigital.gob.es/en, [Accessed by: December 2023]

[Elk94] Elkington, J. Towards the sustainable corporation: Win-win-win business strategies for sustainable development. *California management review*, *36*(2), 90-100, 1994

[EP] The Ecosystem Pie. https://ecosystempie.com/ [Accessed by: December 2023]

[FBC] Flourishing Business Canvas. Flourishing Enterprise Co-lab. https://flourishingbusiness.org/ [Accessed by: December 2023]

[FNS] Dutch program Future Network and Services “futurenetworkservices.nl”, [Accessed by: December 2023]

[Fre84] R.E. Freeman, “ Strategic management: A stakeholder approach.”, Boston: Pitman Publishing Inc., 1984

[HEX] European Flagship project Hexa-X “Main - Hexa-X” https://hexa-x.eu/, [Accessed by: December 2023]

[HEX21-D11] Hexa-X, “Deliverable D1.1: 6G Vision, use cases and key societal values,” Feb. 2021.

[HEX21-D12] Hexa-X, “Deliverable D1.2 - Expanded 6G vision, use cases and societal values – including aspects of sustainability, security and spectrum”, Apr. 2021, https://hexa-x.eu/wp-content/uploads/2022/04/Hexa-X_D1.2_Edited.pdf.

[HEX223-D11] Hexa-X-II, “Deliverable D1.1: Environmental, social, and economic drivers and goals”, June 2023

[HEX223-D42] Hexa-X-II, “Deliverable D4.2: Radio design and spectrum access requirements and key enablers for 6G evolution”, October 2023

[HEX223-D52] Hexa-X-II, “Deliverable D5.2: Characteristics and classification of 6G device classes”, October 2023

[HEX22-D13] Hexa-X, “Deliverable D1.3 – Targets and requirements for 6G – initial E2E architecture”, March 2022, https://hexa-x.eu/wp-content/uploads/2022/03/HexaX_D1.3.pdf

[HEX23-D14] Hexa-X, “Deliverable D1.4 Hexa-X architecture for B5G/6G networks – final release”, June 2023, https://hexa-x.eu/wp-content/uploads/2023/07/Hexa-X-D1.4-Final.pdf

[HEX23-D23] Hexa-X I Deliverable 2.3, “Radio models and enabling techniques towards ultra-high data rate links and capacity in 6G”, June 2023, https://hexa-x.eu/wp-content/uploads/2023/04/Hexa-X-D2_3_v1.0.pdf

[IDA23] IDATE (2023), 5G Indoor: Trends and Challenges, White Paper, https://fr.idate.org/content/uploads/2023/02/5G-indoor-Trends-and-Challenges-White-Paper.pdf

[IFM] IFM, “Safety light curtains and grids technology - ifm” https://www.ifm.com/de/en/shared/technologies/light-curtains/technology

[IPG] IMT 2030(6G) Promotion Group ”IMT-2030(6G)推进组 (imt2030.org.cn)” https://www.imt2030.org.cn/, [Accessed by: December 2023]

[IPG23] IMT-2030(6G) Promotion Group “6G Usage Scenarios and Key Capabilities”, May 2023

[L1480] ITU-T L.1480: “Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors”, Dec 24, 2022

[M.2135] ITU-R Report M.2135, “Guidelines for evaluation of radio interface technologies for IMT-Advanced”, M.2135

[M.2160-0IMT-2030] ITU-R “Framework and overall objectives of the future development of IMT for 2030 and beyond”, Recommendation M.2160-0 Nov. 2023NEW RECOMMENDATION ITU-R M [IMT.FRAMEWORK FOR 2030 AND BEYOND] “Framework and overall objectives of the future development of IMT for 2030 and beyond”, Sept. 26, 2023

[M.2412] ITU-R Report M.2412, “Guidelines for evaluation of radio interface technologies for IMT-2020”, M. 2412

[Mat18] M. Matinmikko-Blue, Stakeholder analysis for the development of sharing-based spectrum governance models. Doctoral thesis. University of Oulu. 2018. http://jultika.oulu.fi/files/isbn9789526220512.pdf

[MET15-D14] METIS Deliverable 1.4 “METIS Channel Models”, METIS D1.4, 2015

[MMM17-D22] mmMagic Deliverable 2.2, “Measurement Results and Final mmMAGIC Channel Models”, mmMagic, 2017

[MSI23] Ministry of Science and ICT (MSIT), “6G Global 2023”, Available at: https://www.msit.go.kr/bbs/view.do?sCode=eng&mId=4&mPid=2&bbsSeqNo=42&nttSeqNo=904, Nov 2023

[MWE16-D51] MiWEBA Deliverable 5.1, “Channel modelling and characterization

[NGA] Next G Alliance “Next G Alliance” https://www.nextgalliance.org/, [Accessed by: December 2023]

[NGA22] Next G Alliance “6G Applications and Use Cases”, May 2022 https://www.nextgalliance.org/white_papers/6g-applications-and-use-cases/

[NGM] Next Generation Mobile Networks alliance “NGMN – We make better connections” https://www.ngmn.org/ [Accessed by: December 2023]

[NGM20] Next Generation Mobile Networks (NGMN) alliance, “NGMN 6G Vision and Drivers Project,” October 2020, https://www.ngmn.org/ngmn-news/press-release/ngmn-board-has-launched-aproject-focussing-on-the-vision-and-drivers-for-6g.html

[NGM21] Next Generation Mobile Networks (NGMN) alliance, “6G Drivers and Vision”, April 2021 https://www.ngmn.org/wp-content/uploads/NGMN-6G-Drivers-and-VisionV1.0_final_New.pdf

[NGM22] Next Generation Mobile Networks (NGMN) alliance, “6G Use-cases and Analysis”, February, 2022. https://www.ngmn.org/wp-content/uploads/220222-NGMN-6G-Use-Cases-andAnalysis-1.pdf

[NGM23] Next Generation Mobile Networks (NGMN) alliance, “6G Requirements and Design Considerations”, February 2023

[OECD18] OECD. 2018. Business models for the circular economy: Opportunities and challenges from a policy perspective. https://www.oecd.org/environment/waste/policy-highlights-business-models-for-the-circular-economy.pdf

[Ost04] A. Osterwalder, The Business Model Ontology: A Proposition In A Design Science Approach (Ph.D. thesis). Lausanne: University of Lausanne, 2004

[P.20240] ITU-R Rec. P.2040-1: "Effects of building materials and structures on radiowave propagation above about 100 MHz", International Telecommunication Union Radiocommunication Sector ITU-R, 07/2015.

[PMI] Precision Medicine Initiative: https://obamawhitehouse.archives.gov/precision-medicine

[QDR] QUAsi Deterministic RadIo channel generator, QuaDRiGa [Accessed by: December 2023]

[RAW17] K. Raworth, A Doughnut for the Anthropocene: humanity's compass in the 21st century. *The lancet planetary health*, *1*(2), e48-e49, 2017

[RC] The Rainforest Canvas. https://www.tuzzit.com/en/canvas/rainforest_canvas [Accessed by: December 2023]

[RES] Italian RESTART PROGRAM “RESTART Foundation (fondazione-restart.it)” https://www.fondazione-restart.it/, [Accessed by: December 2023]

[SBC20] Sustainable Business Canvas. 2020. https://www.sustainablebusinesscanvas.org/ [Accessed by: December 2023]

[SDG] United Nations, “THE 17 GOALS | Sustainable Development (un.org)” https://sdgs.un.org/goals, [Accessed by: December 2023]

[Nor13] G.A. Norris, 2013. The New Requirement for Social Leadership: Healing. in S. Groschl (ed.).Uncertainty, Diversity and the Common Good: Changing Norms and New Leadership Paradigms. London: Gower Publishing. Doing More Good than Harm: Footprints, Handprints, and Beneficience (mit.edu)

[Sic20] SICK AG, White paper “ Safety Light Curtains”, 2020 https://cdn.sick.com/media/docs/4/14/914/whitepaper_sicherheits_lichtvorh%C3%A4nge_mehr_als_gebrauchsgegenst%C3%A4nde_en_im0100914.pdf

[Sit22] Sitra. Sustainable growth with circular economy business models: Playbook for businesses. 2022. https://www.sitra.fi/app/uploads/2022/12/sitra_sustainable_growth_with_circular_economy_business_models.pdf

[SNS] Smart Network and Services “HOME - SNS JU (europa.eu)” https://smart-networks.europa.eu/, [Accessed by: December 2023]

[Sut68] I.E. Sutherland, “A head-mounted three-dimensional display”, Fall Joint Computer Conference, San Francisco, December 1968.

[TWP+20] M. Talmar, B. Walrave, K.S. Podoynitsyna, J. Holmström, A. Georges L. Romme, “Mapping, analyzing and designing innovation ecosystems: The Ecosystem Pie Model, Long Range Planning”, Volume 53, Issue 4, 2020, 101850, ISSN 0024-6301, https://doi.org/10.1016/j.lrp.2018.09.002

[WIN+10-D53] WINNER+ D5.3 “Final Channel Models”, WINNER+ D5.3, 2010

[WIN05-D5.4] WINNER Deliverable 5. 4 “Final Report on Link Level and System Level Channel Models”, WINNER D5. 4, 2005

[WIN207-D112] WINNER II Deliverable D1.1.2, WINNER II D1.1.2, 2007

[ZAM11] C. Zott, R. Amit, and L. Massa, The business model: Recent developments and future research. Journal of Management, 37 (4), 1019–104, 2011