Call: H2020-ICT-2020-2

Project reference: 101015956

Project Name:

A flagship for B5G/6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds

Hexa-X

Deliverable D1.1
6G Vision, use cases and key societal values

Date of delivery:	28/02/2021	Version:	Final
Start date of project:	01/01/2021	Duration:	30 months

Document properties:

Document Number:	D1.1
Document Title:	6G Vision, use cases and key societal values
Editor(s):	Marco Hoffmann, Mikko Uusitalo, Marie-Helene Hamon, Björn Richerzhagen
Authors:	Marco Hoffmann (NOG), Mikko Uusitalo (NOF), Marie-Helene Hamon (ORA), Björn Richerzhagen (SAG), Hans Schotten (TUK), Bin Han (TUK), Patrik Rugeland (EAB), Gustav Wikström (EAB), Panagiotis Demestichas (WIN), Andeas Georgakopoulos (WIN), Volker Ziegler (NOG), Yaning Zou (TUD), Diego Lopez (TID), Pekka Pirinen (OUL), Marja Matinmikko-Blue (OUL), Matti Latva-aho (OUL), Aarno Pärssinen (OUL), Berna Sayrac (ORA), Christian Gallard (ORA), Damiano Rapone (TIM), Giovanna D'Aria (TIM), Leonardo Gomes Baltar (INT), Markus Mueck (INT), Miltiadis Filippou (INT), Michael Bahr (SAG), Tommy Svensson (CHA), Frank H.P. Fitzek (TUD), Riccardo Bassoli (TUD), Emilio Calvanese Strinati (CEA Leti)
Contractual Date of Delivery:	28/02/2021
Dissemination level:	PU[1]
Status:	Final
Version:	Final
File Name:	Hexa-X_D1.1

Revision History

Revision	Date	Issued by	Description
	18.12.2020	Hexa-X WP1	First draft of deliverable D1.1
	29.01.2021	Hexa-X WP1	Deliverable D1.1 ready for review
	26.02.2021	Hexa-X WP1	Deliverable D1.1 ready for submission

[1] PU = Public

Abstract

This report describes the initial 6G Hexa-X vision including first use cases, services, and key value indicator aspects. It will guide the work in the project and will be disseminated globally. This vision will be periodically updated and evolved during the project. The content is based on the following activities: analysis of current trends in society and technology, creation and tuning of the underlying vision, and identification of relevant principles impacting business models.

Keywords

6G vision, use cases, services, key value indicators, performance

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101015956.

Executive Summary

This report is the first deliverable of Work Package 1 (WP1) — "End-to-End Vision, Architecture and System Aspects" — and focuses on the 6G Hexa-X vision including aspects of novel use cases, services and key value indicators and performance.

Major societal and economic trends are analyzed one by one to help to guide research and design for human-centered communication networks in the 2030s. In addition, regulatory and technological trends are critical for the design and deployment of future networks of the 6G era and those are discussed. The 6G Hexa-X vision is to connect the worlds and revolves around their interaction: a human world of our senses, bodies, intelligence, and values; a digital world of information, communication and computing; and a physical world of objects and organisms. The vision has three core values setting the ambitions for the new interactions enabled by 6G: trustworthiness as a backbone of society; digital inclusiveness to connect the unconnected; and sustainability to make the largest possible impact with sustainable global development goals such as energy efficiency and minimum CO_2 footprint. Six main research challenges were identified as integral parts of the 6G Hexa-X vision: connecting intelligence, network of networks (e.g., millions of (specialized) subnetworks), sustainability, global service coverage, extreme experience, and trustworthiness. The relevant principles that impact the business of 6G are identified as part of the vision: the convergence of data, connectivity and local special purpose platforms; new business ecosystems and stakeholders; sustainable ecosystemic platform business models; alternative future business scenarios; and telecommunication and vertical-specific regulations (such as medical regulations).

An initial set of novel use cases envisioned for the 6G era are described including their connection to the 6G Hexa-X vision. The ambition and methodology are presented, as well as a review of the state-of-the-art and existing work on use cases for 6G. Families of use cases are identified and described: sustainable development, massive twinning, tele-presence, robots to cobots, and local trust zones. Each family of use cases addresses several of the six research challenges. The set of use cases described in each of the use case families is representative of envisioned trends for the usage of 6G, but is not meant to be exhaustive and will be enriched throughout the project. An additional family is outlined, including use case enabling services. These services will enable the realization of the use cases identified in the project, and possibly new ones.

The novel concept of Key Value Indicators (KVIs) capturing trustworthiness, inclusiveness and sustainability of 6G on the one hand and 6G as an enabler for sustainability on the other hand is introduced and the effect of the key enabling technologies on value creation for products, services, and society is described. The state of the art on performance and value indicators is reported and research challenges for 6G are outlined across four dimensions: the evolution of Key Performance Indicators (KPIs) to address new use cases, the revolution of new End-to-End (E2E) measures, the need to capture new network capabilities, and the definition of meaningful and measurable KVIs to cover the aforementioned aspects.

The work concludes with an outlook on planned next steps.

Table of Contents

List of Figures

List of Acronyms and Abbreviations

2G	2nd Generation mobile wireless communication system
3D	Three-dimensional
3GPP	3rd Generation Partnership Project
4D	Four-dimensional
4G	4th Generation mobile wireless communication system
5G	5th Generation mobile wireless communication system
5GC	5G Core
5G-PPP	5G Infrastructure Public Private Partnership
6G	6th Generation mobile wireless communication system
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIaaS	AI as a Service
AIMDD	Active Implantable Medical Device Directive
API	Application Programming Interface
AR	Augmented Reality
ARCEP	Autorité de Régulation des Communications Électroniques et des Postes
ATIS	Alliance for Telecommunications Industry Solutions
B5G	Beyond 5G
CAPEX	Capital Expenditures
D2D	Device-to-Device
DMO	Direct Mode Operation
DT	Digital Twin
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
EMF	Electromagnetic Field
EU	European Union
eURLLC	Enhanced Ultra-Reliable Low-Latency Communication
FWA	Fixed Wireless Access
GDP	Gross Domestic Product
GNSS	Global Navigation Satellite System
IAB	Integrated Access/Backhaul
ICNIRP	International Commision on Non-Ionizing Radiation Protection

ICT	Information and Communication Technology
IoT	Internet of Things
IoX	Internet of Everything
ITU	International Telecommunication Union
IVDMD	In Vitro Diagnostic Medical Devices
KPI	Key Performance Indicator
KVI	Key Value Indicator
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
LTE	Long Term Evolution
MBB	Mobile Broadband
MDD	Medical Devices Directive
MEC	Multi-Access Edge Computing
ML	Machine Learning
mMTC	Massive Machine Type Communications
MNO	Mobile Network Operator
MR	Machine Reasoning/Mixed Reality
Mx	Month x after Project Start
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Networks
NTN	Non-Terrestrial Network
NR	New Radio
NWDAF	Network Data Analytics Function
OPEX	Operating Expenditures
OT	Operational Technology
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief
QoI	Quality of Immersion
QoS	Quality of Service
R&I	Research and Innovation
RAN	Radio Access Network
RF	Radio Frequency
RTT	Round-Trip Time
SDG	Sustainable Development Goal
SDN	Software Defined Networking

SDO	Standards Developing Organization
SDR	Software Defined Radio
SLAM	Simultaneous Localization and Mapping
SNS	Smart Networks and Services
TCO	Total Cost of Ownership
TSDCI	Telecommunications Standards Development Society
TSN	Time Sensitive Networking
TTM	Time to Market
UN	United Nations
URLLC	Ultra-Reliable Low-Latency Communication
V2N	Vehicle-to-Network
V2X	Vehicle-to-Everything
VR	Virtual Reality
VRU	Vulnerable Road User
WP	Work Package
XR	Extended Reality

1 Introduction

Hexa-X is one of the 5G-PPP projects under the EU Horizon 2020 framework. It is a flagship project that develops a Beyond 5G (B5G)/6G vision and an intelligent fabric of technology enablers connecting human, physical and digital worlds.

This report is the first deliverable of Work Package 1 (WP1) — "End-to-End Vision, Architecture and System Aspects".

1.1 Objective of the document

The objective of this document is to describe the initial Hexa-X vision on 6G including first use cases, services and Key Value Indicator (KVI) aspects. The content is based on the following activities: the analysis of current trends in society and technology, the creation and tuning of the underlying vision, and the identification of relevant principles impacting business models. The document guides the work in the project (especially of all technology-enabling work packages) and will be disseminated globally.

1.2 Structure of the document

The document is structured in the following way: Section 2 introduces the overall Hexa-X project structure and the structure, main objectives, work plan, and deliverables of WP1. Section 3 describes the common vision including an analysis of current trends in society and technology, the Hexa-X vision on 6G and the identification of relevant principles impacting the business of 6G. Section 4 presents 6G services and use cases, the ambition and methodology of deriving them, followed by an initial description of Hexa-X use case families. Section 5 focuses on KVIs and Key Performance Indicators (KPIs). It includes a mission statement, a state-of-the-art analysis of 6G KPIs and KVIs, as well as a description of Hexa-X challenges and contributions regarding KVIs and KPIs. The document concludes with the description of the planned next steps in Section 6.

2 Project and Work Package 1 Set-Up

In this chapter, the overall Hexa-X project structure, the structure and objectives of WP1, and the WP1 work plan and deliverables are introduced.

2.1 Project structure

The Hexa-X project is structured in nine work packages (see Figure 2-1) spanning a timeframe of 30 months: WP1 —"End-to-End Vision, Architecture and System aspects" — interacts with all the other technical WPs (WP2 – WP7), steering their work and including the research results into a common 6G Hexa-X End-to-End (E2E) view. The technical work packages are focused on design and evaluation of technical enablers and components for B5G/6G. WP8 and WP9 cover horizontal activities related to impact creation and project management, respectively.

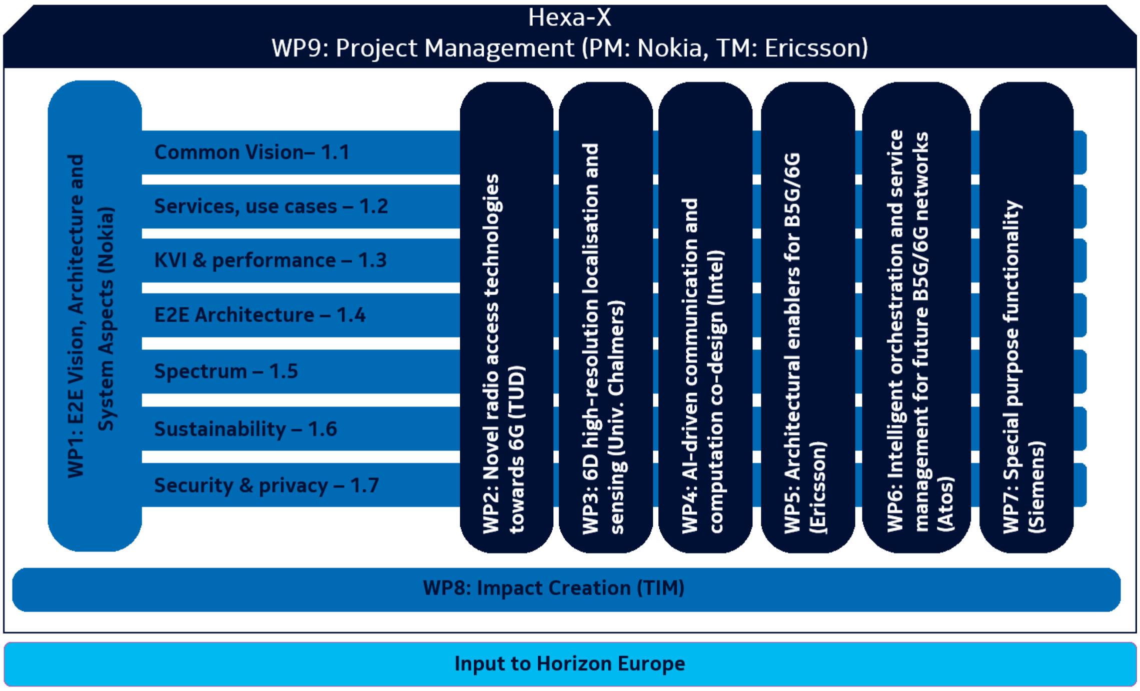

Figure 2-1: ***Hexa-X Project Structure***

2.2 Structure and main objective of WP1

This report forms part of WP1, which has the main objective to define an overall vision, use cases, and an architecture of the x-enabler fabric capable of integrating the technology themes of research connected intelligence, sustainability, trustworthiness, inclusion, and extreme experience. WP1 will guide the work in the whole project and will provide requirements for all other WPs. It covers relevant E2E topics, such as architecture, security, spectrum, KVIs and KPIs. WP1 is split into seven tasks (Task 1.1 – Task 1.7, see Figure 2-1) to achieve its main goal.

2.3 Work plan and deliverables

The set of foundational elements on vision (Task 1.1), use cases and services (Task 1.2), and KVIs/KPIs (Task 1.3) has been integrated to help build a seamless and cohesive 6G Hexa-X vision and architecture.

WP1 will provide the following deliverables:

- D1.1: Initial 6G vision (delivery date: M02, month two after the project start). This report will describe the initial 6G Hexa-X vision including first use cases and KVI aspects.
- D1.2: Initial Hexa-X vision, use cases, and KVIs (delivery date: M04). This report will describe the vision to guide the future research towards 6G. Use cases and KVIs will be identified, providing high-level requirements and definitions of the deployment scenarios. An initial set of sustainability targets, spectrum requirements and security guidelines will also be included.
- D1.3: Hexa-X architecture for 6G networks – initial release (delivery date: M14). This report will include an intermediate status update on use cases, KVIs, and spectrum, as well as achievements with respect to sustainability (final targets and progress of the project vs. targets). A draft of the E2E architecture will be delivered, including a draft security architecture and updated guidelines for security.
- D1.4: Hexa-X architecture for 6G networks – final release (delivery date: M30). This report will present the final Hexa-X vision for 6G, with final use cases, links to the technical work on enablers, final results on sustainability, the E2E Hexa-X architecture including the security architecture and related security guidelines. The document will be disseminated globally to support global discussion on 6G.

All WP1 deliverables are public.

3 Common Vision

3.1 Analysis of current trends in society and technology

3.1.1 Rationale

Since the invention of mobile telephony half a century ago, wireless network technology has undoubtedly transformed the everyday life of billions of people on the planet, and profoundly shaped the economy and the evolution of human society to date. Today, the world is facing several unprecedented challenges in parallel. The prosperity of human society and the long-term survival of mankind are in peril. From climate change, global pandemics, social inequalities to misinformation and distrust of democracy, every aspect that renders today's global economic, societal, and political agendas requires further and sustainable digitalization of the global economy and society. Infused by emerging and disruptive digital technologies on the horizon, wireless networks are and will be the keystone for enabling such a transformation. The evolution journey will carry on in the next decade, with the adoption of 5G use cases at scale with decreasing deployment and operation costs and enabling new and innovative use-case-driven solutions with additional and higher economic and societal values.

At the center of such an evolution is the design of future networks that convey and embody a human-centric (including human-in-control) approach involving human perspectives in all steps of the design [LUM12]. Such human perspectives shall take the environment aspect as a focal point in the consideration. The goals are to not only promote economic prosperity and growth but also act responsibly and to serve the individual and collective needs, interests and values of global society. In particular, facing the unprecedented societal challenges of the 21st century, it is crucial to emphasize and pay great attention to societal and environmental aspects while designing future networks.

In this context, for guiding the design of human-centered future networks in Hexa-X, major societal and economic trends towards 2030 and beyond will be analyzed one by one in the following subsections. In addition, regulatory and technological trends that are critical for the design and deployment of future networks will also be discussed, ensuring the vision and the research work developed in Hexa-X encompass all the essential elements and will lead to a future network design that is deeply rooted in reality and profoundly benefits humanity in the mid-to-long term.

3.1.2 Societal trends towards 2030 and beyond

3.1.2.1 Connectivity for a better and more sustainable world

In 2015, 17 interlinked Sustainable Development Goals (SDGs), as depicted in Figure 3-1, were collectively identified and set for "a better and more sustainable future for all" by the General Assembly of the United Nations (UN) [UN15]. Since then, all sectors of society have been called for working towards and delivering on these goals with a timeframe of 2030. The Information and Communication Technology (ICT) and wireless network industry is one of the major industries that has positively contributed to all the 17 goals so far. For example, it has been estimated that it has helped to lift 2 million people out of extreme poverty in Nigeria during 2010–2016 [GSM20]. GSMA estimates that network technologies enabled a global reduction of around 2,135 million tons of CO_2 emission in many other industries in 2018 alone, which is 10 times greater than the global carbon footprint of the network industry itself.

Developing future networks towards 2030, there is a clear and strong consensus among major stakeholders from industry, academia, and policy makers around the world: network technology shall support and further accelerate this change for a better and sustainable world and network industry will increase its share of contributions and responsibilities to society, enabling significantly increased efficiency in the use of resources and facilitating new and sustainable ways of living in the next decades [Eri20a], [Nok20a], [GSM20], [MAA+20], [Fet20], [Dem20], [Sam20], [NTT20]. The envisioned relations between future networks and the future sustainable development as outlined in the UN SDGs have also been thoroughly analyzed by a group of international experts led by the Finnish 6G Flagship initiative in [MAA+20].

Figure 3-1: ***United Nation's Sustainable Development Goals***

In particular, climate change is an issue that threatens the long-term survival of mankind and will drive major decision making and actions of global governments, industries and citizens towards 2030 and beyond. For example, Europe has set up a Green Deal and announced its ambition to become the world's first climate-neutral continent by 2050 [EC19]. It calls for the development of technologies in a holistic way with net positive impact, e.g., on power consumption and carbon footprint, and even with zero-waste and zero-emission [MAA+20]. In this context, the contribution of the network industry to SDG 13 Climate Action is emphasized with respect to energy performance and carbon footprint. To avoid accelerated energy usage triggered by foreseen exponential increase of traffic it is important to take drastic measures to reduce energy consumption at every element of future networks [Nok20a]. To maintain current development where exponential data growth is possible without increasing the energy usage of networks, striving for that zero load translates to zero power consumption [JM18]. Such reduction has to be further extended to resource and material usage where not only operational consumption but also the consumption of energy and resources during the whole life cycle will be counted for improving sustainability of networks and devices [Eri20a], [EXP20]. Future networks are also expected to have a significant impact on many more societal and industrial sectors (e.g. automotive, industrial, transportation, agriculture, education) by means of complementary innovation, unleashed by the future network capabilities [CB20], [CB20a], [ITU20].

Meanwhile, it is worthy to notice that the SDG framework moves much beyond the climate and calls for a holistic approach to all goals as they are interconnected so it will not be sufficient to focus on SDG 13 alone to support all environmental, social or economic goals [RRS+19]. For guiding the design of future networks further within the SDG framework, it is important to take two additional aspects — trustworthiness and digital inclusion — into account as well, which will be discussed in detail in the next subsections.

3.1.2.2 Built-in trustworthiness in an open society

As communications networks are servicing and intertwined with all everyday processes of social, economic and political life, the need for trustworthiness is apparent. Trustworthiness is also closely related to several of the SDGs, especially #16, "Peace Justice and Strong Institutions" and #9 "Industry, Innovation and Infrastructure", which must rely on trustworthy systems. Trustworthiness ia a human-centric value and a broad term that comes from evidence, while trust is a firm belief. The characteristics of trustworthiness — security, privacy, availability, resilience, compliance with ethical frameworks — are foreseen to become new fundamental requirements for network design towards 2030 [Eri20a], [Dem20]. Future networks have to consider trustworthiness from day one of their design, ensuring that humans will be in control in the age of automation and Artificial Intelligence (AI) and promoting openness, transparency, and mutual trust across different communities and eventually within the global society as a whole.

In addition, there will be increasing business and societal demands for delivering confidential computing solutions, secure handling of identities and protocols, and E2E assurances towards 2030, as networks evolve beyond connectivity platforms towards system platforms that will enable trusted services with special focus on security and privacy. For example, in the next decade or so, digital cash and keys may become a new norm in society. The demand for delivering trustworthiness services will be paramount [Nok20a].

With future networks, beyond communications-enabled services, there will likely be a massive deployment of wireless cameras, radar, radio access with integrated sensing, and other sensing modalities like acoustics with supreme recognition capacity infused by AI and machine vision. The associated privacy concerns must be addressed by, for example, controlling access to data and anonymizing information [Nok20a]. In general, data handling, network intelligence, and the trustworthiness of AI components will be major factors to be considered for designing built-in trustworthiness in future networks [Eri20a].

3.1.2.3 Digital inclusion that serves all populations

Digital inclusion is one of the major enablers for addressing most UN SDGs [MAA+20] such as #1 "No Poverty", #2 "Zero Hunger", #4 "Quality Education", and #10 "Reduced Inequalities" by providing opportunities for the underserved. Developing network technologies towards 2030 with human-centric values and digital inclusion has caught the special interest of stakeholders around the world. It was estimated that nearly half of the world population, i.e., around 3.9 billion, had no broadband access at all as of 2017 (among them 131 million in Europe), where roughly 60% of them are living in rural or remote areas [Phi17]. The remaining 40% are underserved in urban or metropolitan areas that are socio-economically prevented from access. Furthermore, global coverage is very important to address the climate transformation of energy and transport infrastructure as well as for small and medium enterprises outside the metropolitan areas. This includes diverse elements such as support of smart automation services, for example, a fully autonomous supply chain, everywhere on the planet, connectivity for global sensors monitoring the status of forests and oceans, access to digital personal healthcare for everyone, and access to high-end services for institutions (such as schools and hospitals) everywhere [Eri20a], [Eri20b], [Dem20]. More importantly, the global coverage has to be achieved with excellent energy and cost efficiency in both deployment and operation for supporting not only the service of today but also tomorrow [Eri20a], [Dem20].

Evolving towards 2030, connectivity will likely be regarded as a basic human right for accessing equal education, business and health opportunities. Stressed by the pandemic beginning in 2020, there is currently a strong societal, economic, and political drive to continue the expansion of mobile networks for providing full global coverage and closing the digital divide to rural and remote areas [Dem20].

In addition to delivering technology solutions for all populations, it is of the same importance to clearly communicate the benefits and implications of future networks to the public with human-centric values in mind. The first deployments of 5G are facing more reluctance and opposition than previous generations infused by the spread of misinformation on 5G. In order to foster the smooth transition in the deployment of future networks towards 2030, it is very critical to frame 6G research and guide the subsequent design of future networks by clear societal value goals. To minimize the creation and impact of misinformation, the network industry shall involve more representatives of society, who will be end users of future networks, at each stage of their design, and communicate transparently on the expected added value and technical facts to society and to consumers, industry and enterprise customers, public communities, and governments, as suggested in [Dem20].

3.1.2.4 Pervasive AI for human-centric and trustworthy automation and intelligence everywhere

In the next decades, AI is expected to be deployed and used everywhere in society for the improved efficiency and enhanced possibility to solve complex real-life problems in, for example, healthcare and transportation, and for liberating humans from mundane tasks for a better quality of life. This may lead to a simplification of lives where services can be provided automatically and without human intervention [Eri20a], [Nok20a], [NOK20c]. In the connectivity domain, future connected devices will become fully context-aware for more intuitive and efficient interactions among humans, machines and the environment, and the networks will become increasingly advanced at predicting needs, optimizing/simplifying processes and improving operation without or with minimal human participation and supervision [NOK20c], [ZVF+20]. Meanwhile, future networks will also act as a critical infrastructure that transports all the required data and enables the application of AI technologies everywhere.

The integration of such intelligent features in future networks will raise issues such as value alignment, i.e., "human control" and "human trust" in AI, as already mentioned in subsection 3.1.2.2. The design of any digital technology that could potentially expand human possibilities, such as future networks and AI, has to respect and embrace human values, ensuring their positive impact on humanity in the long term [Rus15]. Frameworks for "trustworthy AI" have been developed in Europe (e.g., [ECE19]) and will continue to evolve. It is anticipated that legislation will follow in the next years (e.g., [ECM]), which designates that AI should be lawful, ethical and robust from both societal and technical perspectives. The design of future networks should revisit such works, shape actions based on human-centric and trustworthy AI, and propose enhancements to the frameworks accordingly.

3.1.2.5 Mobile communications as a global ecosystem and success story

Since its second generation, mobile communications and its research have become a true global success story driven by a worldwide joint effort and open collaboration by researchers, technologists, standardization organizations, and companies. Global roaming is, for example, one of the key attributes of mobile communications and an important prerequisite for global use of applications. Standardization is bringing together experts from all over the world, and the 3rd Generation Partnership Project (3GPP) is today one of the most respected standard-developing organizations of the world. The 5G Public-Private Partnership (5GPPP) under Horizon2020 frame program has become a model of industry-academia open collaboration with wide participation from all European countries and significant contributions to the definitions, development and trials of 5G standards [5GP]. To address the sustainability aspect of networks, it would be beneficial to include the resource usage perspective, for example, energy and material to the global standardization.

This success story is challenged today by an increasingly polarized geopolitical context that is affecting the technology industry and global ecosystems to a level that we have not experienced with previous generations. Technology sovereignty, supply chain resilience, cyber security and national security arguments are brought forward and need to be considered. Regional societal policies, for example, with respect to privacy and sustainability, need to be reflected in framing the research agenda and subsequent system design, while at the same time not giving up the common ground for a global standard enabling true global services and benefits through economy of scale.

Hexa-X has the ambition to guide navigation in these troubled waters, advocating the European position of open collaboration and precompetitive joint research.

3.1.3 Economic trends towards 2030 and beyond

Wireless network technology has long been regarded as an important engine for driving global economic growth. With the world moving towards data economy, its impact on global industry and economy is expected to increase in several orders of magnitude. As projected in [Rac20], network technology that encompasses 5G and beyond will potentially trigger $13.2 trillion global sales across ICT industry sectors by 2035, representing 5% of global real GDP, while 6G value chain will be able to generate 22.3 million jobs globally by 2035. This estimation did not even include the impact of connectivity on non-ICT sectors. As recognized in [EC20], “the next era of industry will be one where the physical, digital and human worlds are coming together”, facing great economic and societal challenges towards 2030. Future networks will be a key enabler for such a revolution and must serve as critical digital infrastructure for all industry sectors with advanced technology capability and human-centric design.

3.1.3.1 New applications, new functions, new business models, and new market segments

As in every generation of network evolution, new use cases will arise with 6G, stemming from new applications and new functions. Future networks will be able to integrate localization, sensing, and imaging functions into its system design and provide ultra-high data rates and capacity, which opens a new door for use case and business innovation, for example, holographic communication, future decomposed handsets and wearable devices, and other novel human-machine interfaces with immersive multi-sensory experience [Eri20a], [Nok20a]. Robots will be increasingly present in everyday life, and their usage will no longer be restricted to optimization and automation purposes in the industry, but will expand to various other areas. Integrating the Internet of Things (IoT), Tactile Internet, Internet of Senses and even Internet of Robotics together, future networks will enable not only further deepening of digitalization in all industry sectors but also creating novel consumer products and services such as robotics and sensing-enabled “white goods” [Fet20]. Sustainability will not only become a societal goal but also drive new business cases and use cases for future networks. To serve billions of people who live in rural or in less privileged areas of the cities, new use cases and new business models must be developed along with technology development to provide economically viable and sustainable solutions. Better communication infrastructure and more resilience to harsh climate and harsh environment in remote locations will be essential to local economic growth in poor communities by lowering barriers to economic resources and supporting access to financial services and generating employment opportunities [MAA+20]. Meanwhile, with the expansion of cellular networks into new and specialized subnetworks, both public and private, with novel IoT use cases and future home and enterprise environments, there is an emerging trend to serve new and potentially niche market segments where much more specialized or even tailor-made connectivity solutions will be deployed [NOK20b].

3.1.3.2 Network as a powerhouse for twin ecological and digital transitions

Great challenges as well as great opportunities lie ahead of many industry sectors to progress towards a sustainable future and growth. The key to succeed will be to infuse both ecological and digital transitions simultaneously in those industry sectors [EC20], [EXP20], improve their productivity, and upgrade their capability, efficiency, resilience, and competitiveness with advanced digital technologies. Serving as digital infrastructure of the economy and supporting the flow of gigantic amounts of data, for example., petabytes per year for city areas, the network industry must carry out this twin ecological and digital transition itself, incorporate it into the design of future networks and empower all the other industry sectors for such a transformation towards a sustainable and circular economy [EC20]. To empower true and wide twin ecological and digital transitions, future networks shall be designed with great energy, cost and material/resource efficiency in both deployment and operation phases, and potentially address other important sustainability areas such as biodiversity perspective in its design.

3.1.3.3 Disruptive transformation of global education, skill and labor markets

As shown in the pandemic starting in 2020, many economic activities can continue during the lockdown thanks to advanced digital technologies, and interactions and operations may be handled remotely as easily as locally. Towards 2030, future networks are expected to enable immersive communication combined with a fully digital representation of the physical world, which can allow very precise interaction and feedback loops that can remove distance as a barrier to interaction [Eri20a]. Together with global coverage and other emerging digital technologies, future networks might bring major disruption to global education, skill and labor markets. For example, all schools and universities have to re-think and re-invent themselves to fit into this digital age in terms of both contents and formats of education. Internet of skill may finally come of age, enabling global access in both supply and demand sides in the labor market.

Empowered by automation and intelligence everywhere as well as with new applications, new functions, new business models, and new market segments brought by future networks, new types of jobs will be created, and many existing jobs will be fundamentally transformed [MLC17]. While global automation will lead to replacement of many jobs by AI and machines, it is of paramount importance to educate and promote the right set of vocational skills to all populations and help them prosper in the digital age and data economy.

3.1.4 Regulatory trends towards 2030 and beyond

3.1.4.1 Spectrum and operational aspects

Traditionally, the telecommunications sector has been strongly related to government bodies and has been heavily subject to regulations. Towards 2030, this trend will continue. For example, spectrum management is at the heart of future networks and any wireless technology development, and governments and regulators will have new opportunities due to a wide variety of spectrum bands with highly distinct deployment characteristics and spectrum access models with different levels and needs of spectrum sharing. Another rising issue is Electromagnetic Field (EMF) exposure. The deployment of 5G technology has started in different areas of the world, and in some regions (including Europe) concerns over EMF exposure fuel the opposition of the public to its rollout ([ARC20a], [CON20]). The exposure to EMF is and will be regulated, based on guidelines from the International Commission on Non-Ionizing Radiation Protection (ICNIRP). But some cities or areas of Europe, such as Brussels or Paris or the whole of Italy, have defined more stringent limits, impacting the deployment of networks [GSM14]. Since the beginning of telephony, regulations have played an important role in shaping innovation and the operation of the telecommunications industry, for example, setting the industry to be monopolies in the 1960s, liberalizing the sector with privatization in the 1990s and setting up new regulations for 5G local and private networks. Towards 2030 and beyond, when an exponentially increasing amount of data is being made available from all types of geographical, economical and social contexts, many questions arise including: Who will own the accumulating data? Who will get to decide on technology and who sets the rules and regulations? Future networks will likely combine a range of radio access network (RAN) technologies from macro cells to small cells with very high-capacity short-range links. This calls for refining regulations to resolve inconsistent local approval processes to enable dense small cell deployments. In this context, future network technology could bring unprecedented opportunity for a novel regulatory regime allowing advanced specialized networks in a network-of-networks topology [MAA+20].

3.1.4.2 Ethical aspects

Networks are expected to encompass certain technologies and use cases that are likely to stress current ethical boundaries. For instance, it is envisioned that miniaturized energy-harvesting devices could be injected, ingested or implanted into the human body [MIT10], which would raise concerns of potential health implications, monitoring, and questions of corresponding data ownership. In addition, distribution of ubiquitous sensors and actuators could raise concerns related to their potential excessive resource usage in production, biodegradability, and any long-term effects. Another important aspect will be ethical considerations related to privacy as our lives become further digitalized, and sensors can track our every movement. For each of these aspects, ethics and regulatory actions will need to occur alongside the technological development to avoid backlashes when deploying the technologies. Meanwhile, there is also rising ethical concern over the use of AI as mentioned in Section 3.1.2.4. To address the transparency and the explainability requirements, the European Parliament has recommended the creation of a regulatory body for algorithmic decision-making in 2019 [EPAI].

3.1.4.3 Environmental aspects

There is a growing public awareness of environmental sustainability and the impact of technologies on energy consumption and usage of natural resources. Regulators are addressing the carbon footprint of networks and their related usages. At the European level, the EU Code of Conduct for Energy Consumption [ECC17] sets out the requirements for energy efficiency, and also following the EU's Sustainable Development Strategy, policy background has been studied to facilitate the common methodologies for Product Environmental Footprint [ECS12]. Also the European regulator Radio Spectrum Policy Group has established a sub-group to support action combating climate change [RSP]. At a national level, several initiatives are established; for example, the French ARCEP is working on the definition of a *Green Barometer* in order to inform users of fixed and mobile networks about their consumer behavior as far as their carbon footprint is concerned [ARC20b]. New types of user devices are proposed, based on a modular architecture, allowing renewal of only part of the smartphone to address the demand of circular economy action [FAI], [ECC15]. In Finland, the Ministry of Transport and Communications highlights the need to reduce energy and material consumption within the ICT sector itself and to harness the potential of the ICT sector as a facilitator of a more climate and environmentally friendly society in its final report of preparing an ICT climate and environment strategy [OMH+20].

3.1.5 Technological trends towards 2030 and beyond

3.1.5.1 Disruptive technologies that will shape future connectivity

Convergence of communications, localization, imaging and sensing: Localization was introduced in Release 9 of the 3GPPP specifications and will continue to evolve. With the use of wider bandwidth signals at high band spectrum (>100 GHz) as well as the incorporation of Simultaneous Localization and Mapping (SLAM) with communications at lower frequencies, future networks will be designed integrating high-precision localization (with centimeter-level accuracy), sensing (radar-like but also including spectroscopy and gesture) and imaging (at millimeter-level) capabilities. This requires the development of highly novel approaches and algorithms to co-optimize communications, sensing and/or localization. It will transform not only application layer aspects but also optimize the network performance, for example, with proactive radio resource allocation and management, and determine design choice of waveform to enable both extreme connectivity performance with ultra-high data rate and a full 6D map of the environment that captures information in all three spatial (latitude, longitude, altitude) and orientation (pitch, roll, yaw) dimensions. Combining extreme connectivity and such 6D maps with movement predictions and AI, novel applications and use cases will come to reality that are based on new immersive mixed reality experiences. This enables an intuitive way of interaction and a variety of use cases ranging from medical to industrial context [Eri20a], [Nok20a]. Security and privacy must be integrated into such applications and use cases to ensure that humans will stay in full control of the augmented and mixed reality.

Network intelligence: AI/Machine Learning (ML) will bring a major disruption to future networks from impacting the design of air interface, data processing, network architecture and management towards computing for achieving superior performance [Nok20a], [NOK20c], [Dem20]. It will become essential for the end-to-end network automation dealing with the complexity of orchestration across multiple network domains and layers [ZVF+20]. Network intelligence will help to improve energy efficiency and ensure service availability by performing optimizations that are challenging for traditional algorithms with AI/ML approaches and carrying out system management tasks autonomously with AI/Machine Reasoning (MR) [Eri20a]. However, an autonomous system can only be successful if it is trusted by humans and can be understood and explained. It is extremely critical to establish suitable mechanisms for trustworthy AI. For example: the system needs to be able to explain its actions and why it ended up in its current state; the intelligent system should i) act lawfully, respecting all applicable laws and regulations [ECA18], ii) be ethical, respecting the right principles and values, and iii) be technically robust while considering its social environment. Last but not the least, the system must involve humans when needed [Eri20a].

Network of computing: Future network platforms will bring all physical things into the realm of computing. It will act not only as a connector but also as a controller of physical systems — ranging from simple terminals to complex and performance-sensitive robot control, and augmented reality applications — hosting computing intertwined with communication in a network compute fabric for the highest efficiency [Eri20a]. Ubiquitous universal computing will be distributed among multiple local devices and clouds [Nok20a], [ZVF+20]. Service providers can utilize their assets by integrating compute and storage into increasingly virtualized networks to provide applications with maximum performance, reliability, low jitter, and millisecond latencies. A network-compute fabric can provide tools and disruptive services that are supported beyond current connectivity solutions, such as accelerated compute and data services and new services that are enabled by disruptive technoloiges such as joint sensing and communications and digital twins for customer segments and verticals, including enterprises and industries [Eri20a].

Resilience and security: Network resilience that helps the network to provide and maintain an acceptable level of services facing faults or challenging situations will need to be addressed from different perspectives. Applications that demand resilience, both for their connectivity and their end-to-end communication, need to be supported. A distributed architecture may ensure that not all information (and not all risk) is centralized among a few parties. Similarly, the necessary internet infrastructure needs to be available, resilient, and resistant to commercial surveillance [Eri20a]. It will be critical to ensure the integrity of the entire system including both RAN and Core parts [Fet20]. In addition, associated with their impact on the economy and society, future networks are expected to face more frequent and more sophisticated cyber-attacks and security breaches. New and efficient security and privacy schemes need to be developed [Nok20a], [Fet20], for example, applying AI to predict problems, detect and automatically resolve attacks that are caused by either classical or AI-based approaches, [Dem20]. Last, but not least, resilience and security-enabled trustworthiness can only be fully realized when it is embedded in both the corresponding software and hardware implementations of the network technology [Fet20].

Digital Twin: A Digital Twin (DT) is a digital replica of a living or non-living entity. The virtual representation reflects all the relevant dynamics, characteristics, critical components and important properties of an original physical object throughout its life cycle. The creation and update of DTs relies on timely and reliable multi-sense wireless sensing (telemetry), while the cyber-physical interaction relies on timely and reliable wireless control [MLC20] over many interaction points where wireless devices are embedded. In future networks, DTs will be used as a valuable tool to create novel and disruptive solutions, especially for vertical industries, that are enabled by a large scale of real-time, robust and seamless interactions among, for example, machines, humans and environments. Particularly, DTs can be scaled up, which enables a large scale of sustainable living with systematic climate mitigation measures, improves the resilience of society in crisis situations by actively monitoring and simulating all possible scenarios and potentially helps transform the whole societal structure that is suitable for 2030 and beyond.

3.1.5.2 Technology evolution towards cost reduction and improved efficiency

Reimagined network architecture: New network architecture paradigms involve sub-networks and RAN–Core convergence [ZVF+20]. All future deployment scenarios will rely on a superior transport network that is flexible, scalable and reliable to support demanding use cases and novel deployment options, such as a mixture of distributed RAN and centralized/cloud RAN enabled by AI-powered programmability [Eri20a]. The network architecture shall provide the capability to facilitate all the AI operations in the network.

Predictable latency and reliability: Future networks shall address the extreme performance requirements of more advanced vertical industry applications on latency, reliability and potentially, age of information and age of task [NOK20b]. To achieve such extreme performances with reasonable costs requires a joint design of communications, control and even computing [Fet20], [HYJ+20]. To address less extreme requirements, a deterministic latency end-to-end across the protocol stack will be important for enabling cost-efficient services.

New devices and interfaces: Future networks will be connected to multitudes of devices and interfaces beyond mobile phones or computers, enabling novel human-machine/machine-machine/AI-AI communications. New human-machine interfaces created by a collection of multiple local devices will be able to act in unison [Nok20a]. In addition, the ubiquity and longevity of IoT devices will be further enhanced through zero-cost and zero-energy devices where printable, energy harvesting devices can be deployed anywhere.

Component and hardware: With advances in hardware development, it is now possible to employ generic hardware acceleration for faster service deployments through cloudification and virtualization. On the other hand, the use of non-generic hardware acceleration will still continue to address high performance required by AI and the real-time 6G physical layer, for example. Meanwhile, novel research on metamaterials promises potentially revolutionary new applications, questioning long-held presumptions based on classical components, for example, reconfigurable surfaces or novel antenna designs [Eri20a]. Towards 2030, to minimize power consumption and enable novel use cases and seamless interactions, novel and advanced component/hardware technologies will continue to be developed.

Software: Application development for enabling functions and services will become easier than ever. There will be a need for the ecosystem to develop new, innovative applications once more things get connected. More development flexibility will be required to meet the increasing need for highly customized applications. Common APIs and abstractions, together with new programming concepts and simplified models, will be part of the solution [Eri20a]. Open source and open APIs may play an important role to foster the growth of ecosystems.

Spectrum: More dynamic spectrum sharing methods are appearing (e.g., CBRS [CBR]) where spectrum resources are dynamically allocated in time and space. It is straightforward to follow this evolution forward into a more demand-driven system concept with a smaller granularity in spectrum allocation and a shorter round-trip time. This can allow for smarter use of resources complementing licensed and unlicensed bands and an opportunity for mobile services to use spectrum resources in bands occupied by other services [Nok20a], [Eri20a].

Digital inclusion: Low-cost and power-efficient terrestrial solutions and/or non-terrestrial networks (NTNs) will be required to provide coverage for humans and machines in rural and remote areas, for example, with high-altitude platforms, Low Earth Orbit (LEO) satellites, and Device-to-Device (D2D)-based crowd networking [Dem20]. Currently, 3GPP is working on including NTN in the 5G New Radio (NR) scope in Release 17, while several LEO initiatives are actively promoting NTN as a useful coverage complement to terrestrial high-capacity systems [Eri20a].

Context-dependent services and applications: Introduction of special purpose networks and the explosive emergence of new verticals-driven applications create richer user experience depending on the time and place. Service offerings become different regarding requirements and depending on the context and end user devices must be able to proactively utilize varying content offerings. This gives rise to different microservices offered by different players depending on the specific ecosystem. Agent technology-type solutions will serve users depending on the desired application profiles, which also vary from work mode to leisure time, etc.

3.1.6 Most significant global activities on future connectivity

With significant impacts on society, economy and politics towards 2030, the global race on the research of 6G networks has already started. The International Telecommunication Union (ITU) has established a focus group on Technologies for Network 2030 in 2018 [ITU18] and the Next Generation Mobile Networks (NGMN) alliance announced the launch of a project on visions and drivers for 6G in February 2021 [NGM21].

In Europe, with support of the academy of Finland, the world’s first national 6G program, 6G Flagship, was established at the University of Oulu in 2018 [6GF], [6GF19]. In January 2021, nine EU 6G projects (including Hexa-X) kicked off under the last call of Horizon 2020 with a total budget of €55 million [ICT52]. It is expected that these projects will carry out explorative research and pave the way towards 6G. Meanwhile, building on activities and results of 5G-PPP in Horizon 2020, a renewed European level private-public partnership on Smart Networks and Services (SNS) joint undertaking will be launched in the spring/summer of 2021 under the 2021–

2027 European Research Frame Programme, i.e., Horizon Europe, targeting at R&I beyond 5G and towards 6G [SNS]. In addition to network design, with 2030s on the horizon, Europe has also recognized the importance of strengthening its industry position and competence on connectivity chip design. A cross-industry initiative — COREnect — was then launched in July 2020, bringing European major players in microelectronics and telecommunications together and targeting the reduction of Europe's dependence on other continents for suppling electronic subsystems and components towards 6G [COR].

Meanwhile, outside Europe, with "Secure 5G and Beyond Act" published in March 2020, the US administration has officially announced its intention to work with the private sector to facilitate the evolution and security of 5G [5GA]. On 13 October 2020, the Alliance for Telecommunications Industry Solutions (ATIS) launched Next G Alliance, an industry initiative that builds foundations for US leadership in 6G and beyond with 16 industry founding members [NGA]. In Asia, as announced in September 2020, South Korea will target to invest €142 million over 5 years from 2021 to secure high-risk basic 6G technology [Kor20], while Japan published a paper on "beyond 5G promotion strategy – roadmap towards 6G" for public consultation in June 2020 [JAP20], and China's Ministry of Science and Technology made in a statement in 2020 that it will set up two working groups to carry out research on 6G covering both policy and technical aspects of 6G development [CHI20]. Recently, the Telecommunications Standards Development Society, India (TSDCI) has started to establish a 6G initiative with focus on 6G use cases and requirements [TSD20].

3.2 Hexa-X vision on 6G

During the last half century, driven by continuous wireless innovations and by market needs, mobile networks and the telecommunications industry have significantly transformed human society and the lives of billions. The primary focus is always to meet peoples' needs to communicate anywhere/anytime. Since the time of 4G, the focus was on delivering a digital infrastructure that also supports professional services, vertical sectors and machine-to-machine communication. With the advent of 5G, this move has considerably been amplified. 5G is expected to pave the way for the digitalization and transformation of key industry sectors like transportation, logistics, commerce, production, health, smart cities, agriculture and public administration. This trend of digitalization, making industries more connected, automated and smart [Bar19] in conjunction with consumer interest in increasingly demanding services such as Augmented Reality (AR) and Virtual Reality (VR) will continue. Therefore, the need of services for connectivity is expected to keep growing exponentially [Eri20c], and will call for bit rates in the order of hundreds of gigabits per second to terabits per second. Several additional aspects of performance will be described below.

While 4G has enabled and 5G significantly enhanced our ability to consume digital media anywhere, anytime, the technology of the future should enable us to embed ourselves in entire virtual or *digital worlds*. In the world of 2030, human intelligence will be augmented by being tightly coupled and seamlessly intertwined with the network and digital technologies.

With advances in AI, machines can transform data into reasoning and decisions that will help humans understand and act better in our world. As the domestic and industrial machines of today transform into swarms of multi-purpose robots and drones, new verticals based on human-machine haptic and thought interfaces to control them from anywhere should become an integral part of the future networks. As illustrated in Figure 3-2, Hexa-X envisions a future in which everyday experience is enriched by the seamless **unification of the *physical, digital* and *human worlds*** achieved through a new ecosystem of networks, sub-networks and device technologies.

Such a transformation will undoubtedly generate unprecedented economic opportunities towards the 2030 timeframe. To this end, 6G research should address studies into the fundamentals, design, realization, application and market opportunities of future communications systems. Multiple key requirements must be reconciled to serve the massively growing traffic and the exploding numbers of devices and markets both in current deployment areas and for the currently underserved. At same time there is the need to accomplish the highest possible standards regarding sustainable energy and resource efficiency, low latency, strong security, and efficiency in deployment (coverage) and operation, for enabling sustainable growth in a trustworthy way. Despite increasing ambitions with more use cases and more performance, 6G should be an integral part of a fully sustainable and carbon neutral world. The main motivation factors for the 6G vision are:

Technology push: The advent of key technologies such as AI, radio access beyond 100 GHz, network virtualization, cloud native implementation and architectural disaggregation concepts promise to add important abilities and design dimensions for wireless networks. A timely start into a technology and concept evaluation is required, even if some of these technologies are still on a low Technology Readiness Level, to understand the potential performance and impact on the overall system architecture. It is crucial to apply these new technologies to excel in new usage domains, and to make them useful in the future society.

Society and industry pull: Climate change, pandemics, the digital divide, social inequalities, as well as distrust and threats to democracy, are some of the unprecedented societal challenges of our times. It is of utmost importance to mitigate these devastating challenges, while also creating opportunity for innovation-led growth and employment. Wireless networks, being the central component of a digitalized society, must reflect such complex needs and opportunities and proactively provide sustainable digital solutions [WEF20] to help address United Nations (UN) [UN19] and European SDGs [EC19]. Digitalization of industry sectors will continue to improve efficiency, trust in and resilience of the economy, promote sustainable growth and create meaningful jobs, supporting the transformation of Europe to a strong circular economy.

In light of the above, the 6G flagship initiative Hexa-X has been established by bringing together the key industry stakeholders, along with the full value chain of future connectivity solutions ranging from network vendors, operators, verticals, and technology providers as well as the most prominent European research institutes and universities in this domain, streamlining expert forces and creating a critical mass to lead an integrated effort of research and development towards 6G.

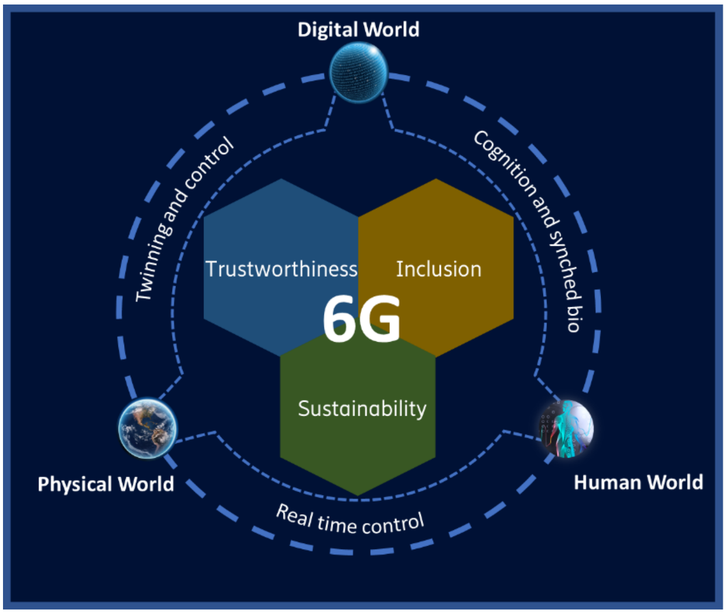

Figure 3-2: ***Hexa-X 6G vision***

The Hexa-X vision for 6G revolves around interactions between three worlds: a *human world* of our senses, bodies, intelligence, and values; a *digital world* of information, communication and computing; and a *physical world* of objects and organisms. The future 6G network system should make it possible for these worlds to tightly synchronize and integrate to make it possible to seamlessly move between them. Realizing these interactions will open up many new use cases, applications, and services that will benefit people on all levels: as consumers, parts of enterprises or societies.

Interactions between the physical and the digital world will enable digital twins of the world, where rich sensor information can be used for deep data mining and analysis. Intelligent agents can act on the digital twin and trigger actions in the physical world through actuators. Such actions would improve the efficiency and resilience of operation in the physical world via better planning and control as well as preventive actions, for example for maintenance before problems would emerge. This could lead to a massive scale of usage of digital twins and hence massive needs for communication.

Interactions between the human and physical world would enable efficient control and feedback between the worlds, for example based on efficient human-machine interfaces.

Interactions between the human and digital world enable assistance from AI to improve our lives, as well as empowering fully immersive communication between people. Collection of information on the state of the human bodies and synching this from the human world to the digital world would entail getting knowledge of the body through e-health applications, enabling, for example, preventive healthcare.

Importantly, the vision has three core values at its center, around which the three worlds revolve (see Figure 3-2), setting the ambitions for the new interactions enabled by 6G. These are: *trustworthiness* for 6G as a backbone of society; *inclusiveness* for 6G to be available for everyone and everywhere; and *sustainability* for 6G to play the largest role possible towards global development with regard to environmental, social and economic aspects. These three core values should influence the targeted 6G capabilities and requirements and should together with the three world interactions guide the project. Taken together, the vision points towards a set of research challenges to be addressed by the project, presented next.

To fully embrace such a vision, Hexa-X recognizes the necessity to expand the fundamental network design paradigm from mainly performance-oriented to both performance- and value-oriented. Here *value* entails intangible yet important human and societal needs such as sustainability, trustworthiness and inclusion. This will lead to a new class of evaluation criterion, i.e., KVIs, which must be understood, developed and adopted in framing 6G research and the network design towards 6G. Hexa-X understands that the development towards 6G requires wide support and global efforts. It will strive for openness and collaboration among the European and global research community, standardization bodies, and policy makers through, for example, organization of public workshops, preparation of joint whitepapers, and active participation in major events. An open, modular and flexible framework — the x-enabler fabric — will be developed as a foundation, to integrate and weave together the technical enablers that address the six research challenges, from both the Hexa-X project itself and other 6G projects. "X" in Hexa-X refers to exploring the unknown and the x-enabler fabric adds the dimension of "x" as "cross-enabler". The realization of a new network generation takes about 8-10 years, and to guide the Research and Innovation (R&I) globally towards 6G during this time, Hexa-X will lay the foundation for the network of 2030 and develop long-term strategic roadmaps based on research outputs obtained within the Hexa-X project as well as from other 6G research projects under the H2020 5G-PPP umbrella.

3.2.1 Research challenges

In order to ensure that the 6G research progresses in the right direction to fulfil the needs of 2030, it is important to focus on the most relevant issues. In this vision, six main research challenges were identified as can be seen in Figure 3-3. These challenges must be addressed to lay the technical foundation for the wireless systems of the 6G era:

Figure 3-3: ***6G research challenges***

1. **Connecting intelligence**: 6G shall assume a crucial role and responsibility for large-scale deployments of intelligence in the wider society. 6G shall provide a framework to support

(e.g., through advanced resource management), enhance (e.g., through supplementary data, functionality, insights), and, ultimately enable real-time trustworthy control – transforming AI/ML technologies into a vital and fully trusted enabler for significantly improved efficiency and service experience, with the human factor ("human in the loop") integrated.

2. **Network of networks**: 6G shall aggregate multiple types of resources, including communication, data and AI processing that optimally connect at different scales, ranging from, for example, in-body, intra-machine, indoor, data centers, to wide areas networks. Their integration results in an enormous digital ecosystem that grows more and more capable, intelligent, complex and heterogeneous, and eventually creates a single network of networks. It will serve various needs, support different nodes and means of connectivity, and handle mass-scale deployment and operation fulfilling a large diversity of requirements with utmost efficiency and flexibility, promoting business and economy growth and addressing major societal challenges like sustainable development, health, safety and the digital divide.
3. **Sustainability**: 6G shall transform networks into an energy-optimized digital infrastructure and will deeply revise the full resource chains of wireless networks towards sustainability and carbon neutrality. Its digital fabric shall, beyond providing unprecedented connectivity and coverage, also create the ability to sense and understand the state of the physical world in real time, and as such boost sustainability from the environmental, economic, and social perspectives and importantly deliver effective and sustainable digitalization tools for global industry, society and policy makers, help achieve UN SDGs and assist the implementation/operation of the EU Green Deal, in particular after the COVID-19 pandemic, towards a circular economy and a sustainable world.
4. **Global service coverage**: 6G shall put digital inclusion as one of the top priorities and encompass efficient and affordable solutions for global service coverage, connecting remote places, for example, in rural areas and in transport over oceans or vast land masses, enabling new services and businesses that will promote economic growth [AEM12] and reduce the digital divide as well as improving safety and operation efficiency in those currently under-/uncovered areas.
5. **Extreme experience**: 6G shall provide extreme bit rates (access in the order of hundreds of gigabits per second to a few terabits per second), extremely low (imperceptible) latencies, seemingly infinite capacity, precision localization and sensing, pushing the performance of networks a leap beyond what is possible with 5G – unlocking commercial values of new technologies at sub-THz range, supporting extreme experience of services such as fully immersive communication or remote control at scale, and accelerating the pace of digitalization.
6. **Trustworthiness**: 6G shall ensure the confidentiality, integrity and availability of end-to-end communications, and guarantee data privacy, operation resilience and security, building trust of wireless networks as well as its enabled applications among consumers and enterprises — supporting and promoting European values of trust and privacy protection as well as the technological EU sovereignty goal for fostering an open, trustworthy and democratic Europe in the digital age.

Naturally the requirements of cost-effective deployability and operability always apply in order to realize the results from these research challenges.

3.3 Aspects of 6G business impact

The identification and development of future business opportunities will be an important aspect in 6G research and development to address the needs of various vertical sectors that today are learning to benefit from 5G. This will call for filling in the requirements of scalability, replicability and sustainability in a legitimate way in a platform ecosystem of converging connectivity, data and specialized services. Development of new ecosystemic platform business models has to be done in a sustainable way. Business ecosystems that aim to bring together stakeholders to solve systemic sustainability problems will require an open ecosystem-focused value configuration and decentralized power configuration where there is no single dominating stakeholder, but the roles and positions will vary depending on the problem at hand. Focus will increasingly be on the long tail of specialized user requirements that crosses a variety of industries [YAM20a].

A major challenge is in how 6G could become a truly general-purpose technology, i.e., potentially strongly and widely affecting the world economy, instead of simply an enabling technology, to support countries, organizations and society in the journey towards a sustainable future. The achievement of the UN SDGs by 2030 calls for the whole ICT sector to support the verticals in renewing their operations to meet the increasing requirements for sustainability [MAA+20], [ZY20]. The deployment of 6G is expected to start in 2030 when the current SDGs should be achieved. The UN SDG framework itself is likely to evolve during the full deployment of 6G in the 2030s.

3.3.1 Convergence of data, connectivity and local special purpose platforms

With the beginning of the 5G era, mobile communication networks have evolved into multi-purpose business platforms of cross-sectoral relevance. The mobile connectivity platforms of the Mobile Network Operators (MNOs) acquired from the network vendors are increasingly becoming converged with the data platforms of cloud service providers, giving rise to new platform-based ecosystems [AYM+20]. The convergence of data and connectivity platforms continues to be a major influencer for the business of 6G and the related value-capture in the 6G era requires understanding the dynamics of platforms and ecosystems [MYP20]. In addition to wide area networks based on distributed multi-stakeholder cloud architecture, we will see millions of subnetworks designed for both autonomous operation as well as operation in co-ordination with wide area policies. Operator-assisted service discovery and function offloading will enable an expansion of platform-based ecosystems beyond the dimensions of data and connectivity. Performance attributes such as extreme reliability and low latency can be associated with specialized and localized subnetwork platforms for the 2030s. Access to data and data ownership continue to be major factors shaping the business around 6G, and limiting which stakeholdes can make use of data is a means of controlling the ecosystem. Modularity and complementarity of technology solutions raise difficult openness and transparency as well as collaboration vs. competition issues in the future 6G business ecosystem. The resulting complex multi-stakeholder ecosystem will be an arena of dynamic use case instantiation and monetization.

3.3.2 New business ecosystem and stakeholders

Combining various data platforms, connectivity and local special purpose platforms is a great opportunity to enable new business ecosystems beyond the mass market paradigm; but it is also a challenging task, especially in the real-life complex multi-stakeholder environments in verticals where different organizations typically have their own data, connectivity and special purpose operations time platforms with interactions with outside platforms being limited. The business ecosystem around future mobile communications is changing with evolving stakeholder roles and new stakeholders emerging [AYM+20], [ZY20]. The serving of different verticals with local and often private 5G networks has already introduced new stakeholders as local operators to complement the MNOs [MLA+17]. For example, local operators are appearing to serve a closed industry setting in a factory, MNOs' customers in a local public network, or a mix of both customer groups. Future 6G business ecosystems for solving sustainability problems need open value configuration and decentralized power configuration focusing on specialized user requirements that cross a variety of industries [YAM20a], [YAM20b]. Different sets of stakeholders with their specialized expertise and resources come together in the 6G ecosystem to solve specific sustainability problems.

3.3.3 Sustainable ecosystemic platform business models

In 6G the focus is on developing economically, societally and environmentally sustainable solutions and business models and with special potential for specialized solutions tailored to specific context and need.

The solving of sustainability problems with 6G-based solutions emphasizes the business ecosystem level that brings the needed stakeholders together, instead of focusing at a single organization's level [YMA20]. As a result of the growing ecosystem level emphasis in 6G, the development of business models in the ecosystem level will be increasingly important, shifting the focus to ecosystemic platform business models. There the scalability and replicability of the 6G solutions' business models are key in determining the success. A scalable business model is agile and provides exponentially increasing returns to scale in terms of growth from additional resources applied, while a replicable business model can be copied to several markets simultaneously with minimum variations.

3.3.4 Alternative future business scenarios

Business scenarios present alternatives for the future, which is unknown. A set of 12 alternative business scenarios were developed for 6G in [YAM20a], [YAM20b], [ZY20]. From the scenarios, especially the most plausible "MNO6.0" Scenario and the most preferred "Sustainable Edge" scenario present highly distinct views for the future. The MNO6.0 scenario is built on the use of MNOs' wide existing customer base, with a growing demand for capacity through investments to maintain and strengthen their customer base and market position in connectivity, enhanced with customer data, relying on efficient spectrum usage and a variety of specialized attributes of performance.

The sustainable edge scenario [YAM20a], on the other hand, describes a future where novel players take over both customer ownership and networks and MNOs play a role as a wholesale connectivity service provider. New, local, and specialized demands provide an opportunitity for novel business segments, specializing in governmental, municipal, vertical or enterprise customers and vertical differentiation with increasing requirements for sustainability in specific industry segments like education, healthcare and manufacturing. Also thinking and acting locally, close to the customer, promoting resource sharing, and utilizing the lowest cost spectrum and virtualized cloud infrastructure are key in the business scenario. In addition, we will see the proliferation of private and campus scenarios privately run and operated using either unlicensed or licensed spectrum.

3.3.5 Telecommunication and vertical specific regulation

A key influencer of business of 6G continues to be regulation, which defines the rules and conditions for the telecommunication network as well as the different verticals making use of the data and connectivity platforms. The telecommunication sector is highly regulated, including, for example, spectrum regulation, access regulation, pricing regulation, competition regulation, privacy and data protection (see e.g. [MLA+18], [5GP20]). Additionally, the regulatory environment for 6G in vertical services is complex, encompassing both the connectivity-oriented communications market as well as specific vertical services offerings and performance attributes, so requiring a large variety of regulatory challenges to be addressed within the proper bodies. Moreover, the growing pressure from sustainability on environmental aspects, for example, will influence the development of future 6G networks. In Hexa-X we will consider the evolution of the spectrum requirements and of the current spectrum usages, in order to guarantee future-proof migration paths for vertical services, for example, and to enable new business opportunities. Deliverable D1.2 will look into the future alternatives of the business of 6G in more detail.

4 Services, Use Cases

This chapter outlines the initial set of use cases envisioned for the Hexa-X project, and their connection to the vision described previously. This first set of use cases is not meant to be exhaustive, but representative of use cases envisioned for 6G. It will be updated and enriched throughout the project.

4.1 Ambition and methodology

4.1.1 Mission statement

The 6G vision defined in Hexa-X is built on the interactions between the three worlds intertwined, namely the physical, digital and human worlds, and these interactions are driven by three core values, shared by European players and Hexa-X members, *sustainability*, *inclusiveness* and *trustworthiness*. In order to design the 6G system, which would realize this vision and play a crucial role in the development of society towards more sustainability, inclusiveness and trustworthiness, a first step consists in defining relevant use cases. Hexa-X use cases should not be only a simple extension of the 5G use cases, but should outline new usages, based on a more inclusive (along the geographical as well as the societal axis) and more sustainable use of the technology. To be in line with the vision, the set of use cases will relate to the six research challenges described in Chapter 3. These use cases will allow the requirements applying to the 6G network to be derived and the specification of the Hexa-X technical enablers to be driven to meet the target KPI/KVI values.

4.1.2 Terminology

The use cases considered in Hexa-X are real-life applications of the physical, human and digital worlds. Use cases may support one or more applications of the three worlds, through a clearly defined set of KPIs and KVIs (see Section 5) and should apply to one or more verticals. The "real life" aspect is highlighted in the use case descriptions, as this helps the wider audience appreciate the everyday life applications of the demanding technical KPIs that Hexa-X aims to achieve.

4.1.3 State-of-the-art

In 2020 (and even earlier), some stakeholders of the mobile ecosystem have started sharing their views about 6G. The white papers and other publications available already give some hints on use cases targeted with 6G. This section gives an overview of the most cited ones in the selected references.

Building on top of the 5G trend and the advent of VR and AR, Extended Reality (XR) will develop in many different areas such as "entertainment, medicine, science, education, and manufacturing industries" [Sam20]. Such techniques require not only huge data throughputs, low latency and positioning capability in order to provide a high-quality user experience but also specific device features like compute and battery. Such devices could be "lightweight glasses that project images onto the eyes" [AKN20]. Going a step further, holographic representations of objects and people are imagined [Sam20], [AKN20], [Eri20a]. The "multi-sensory holographic teleportation" [AKN20] wording is even used, meaning that beyond 3D representations of distant objects or people, all the senses are also transmitted; for example, you could attend, remotely, a meeting with your colleagues, all being present in the same meeting room, hearing discussions, smelling as if you were physically yourself in the room [Sam20], [Flag19]. As mentioned in [Eri20a], this could nicely help to cover the communication needs of the society, even in difficult situations such as the COVID-19 pandemic.

In order to support this holographic use case, a digital representation of the physical world, based on sensors and AI technologies, may be needed; this digital replica is called a digital twin. Actions in real life via interaction with its digital twin are even considered [Sam20]. In [Eri20a], a 4D spatio-temporal interactive map of a city could enable the realisation of actions in the "real" city, such as sending commands to public transport, waste handling, or water and heating management systems.

One of the key concerns of the society coming with the development of new technologies is that its related services must be accessible for all and everywhere they are needed. This digital inclusion requirement does not only mean "global coverage" (at an affordable cost in terms of deployment and for the customer as well) but also "easy-to-use technology", for example, for the elderly or people with disabilities.

Such a need is already nicely identified in 6G use cases such as high-grade digital oasis [Eri20a] or distance education [NTT20], sensors monitoring the status of forests and oceans [Eri20a], or telemedicine and healthcare in rural areas not properly connected yet.

Usage of telemedicine has indeed been generalized during the COVID-19 pandemic. One of the side effects of the COVID-19 pandemic is that, during lockdown periods, people are not keen to go to the doctor, even if they have health problems that would require a consultation; it is unfortunately expected that the number of deaths due to non-detection of cancers on due time will increase in the coming years (e.g. see [MSM+20]). In order to avoid such situations, the development of telemedicine and remote consultations appears as a good alternative, especially in rural or challenging areas [NTT20]. Beyond this simple use case, 6G is also expected to foster the development of e-health applications, thanks to in-body devices, such as biosensors to monitor health conditions such as heart rate or blood pressure [Flag19], [Eri20a], [NTT20]. The network will allow remote analysis and processing to adjust the medical treatment accordingly.

5G allows for improved efficiency in industrial process, and connected robots represent one of the most emblematic use cases [ACI20]: mobile robots handling materials in warehouse and production plants, extremely large autonomous guided vehicles in chemical plants, etc. The usage of connected robots is expected to develop more in a 6G perspective and extend as well to other fields: collaborative industrial AI partners could take care of tedious or dangerous tasks, and even cooperate with human beings [Eri20b]; swarms of small robots will perform domestic chores in home networks [VM20].

These use cases represent major trends in the literature for 6G, but the list is not exhaustive, as more and more actors share their vision on future usages for 6G. Hexa-X will go one step further, beyond individual viewpoints, and will bring a unified view on these use cases for 6G, sharing the perspectives consolidated among a whole consortium of partners.

4.1.4 Methodology

This deliverable provides an initial set of use cases as a starting point for the technical work within the project. This set of use cases was reached from a combination of top-down (relying on the vision, the core values and research challenges as a basis to select use cases) and bottom-up approaches (collecting views from the ecosystem through proposals from partners, state-of-the-art, defining new use cases to illustrate the use of new technologies). The set of use cases has been clustered into families of use cases. These families of use cases describe use cases involving similar interactions and answering one or several of the six research challenges. The use cases grouped in one family are expected to share similar requirements. These families of use cases will be consolidated iteratively, among the partners and with the Advisory Group.

4.2 Hexa-X families of use cases

4.2.1 Overview of Hexa-X families of use cases

The Hexa-X vision describes the envisioned role of 6G in the evolution of society. The vision and the associated six research challenges lay the foundations on which relevant use cases for 6G can be forecasted, accounting also for the societal and economic trends (see Section 3). Hexa-X partners built on this vision to identify an initial set of use cases as a first baseline to guide the technical work within the project. This first set of use cases is not exhaustive but a first set of representative use cases, which will be refined and extended. These use cases encompass a wide range of usages, from evolutionary ones, extending and enriching the 5G usages with new capabilities, to more disruptive ones, opening up new horizons where 6G could benefit and transform society. These use cases are clustered into families of use cases, according to the type of usages and research challenge addressed, as pictured in Figure 4-1. Trustworthiness is a common value shared by all families of use cases, as well as sustainability. Global service coverage is the other value emphasized in the Hexa-X vision, and different use cases, gathered in a use case family ***Sustainable development***, illustrate how 6G can contribute to the transformation of society, targeting UN sustainable development goals and the EU Green Deal, providing global access to digital services and energy-optimized infrastructures and services. ***Massive twinning*** is another use case family involving the massive use of digital twins to represent and control the physical world. The Telepresence use case family covers immersive telepresence for enhanced interactions, involving mixed reality or merged reality, providing extreme and fully immersive experience. The use case family ***Robots to cobots*** includes various use cases involving interacting robots, at home to facilitate everyday life as well as in professional environments to improve the efficiency of processes. 6G will also integrate multiple sorts of networks and handle the complexity and heterogeneity of a network of networks. The use case family ***Local trust zones (for human and machine)*** encompasses different use cases, involving nanoscale in-body networks to wide area deployment of sensors networks.

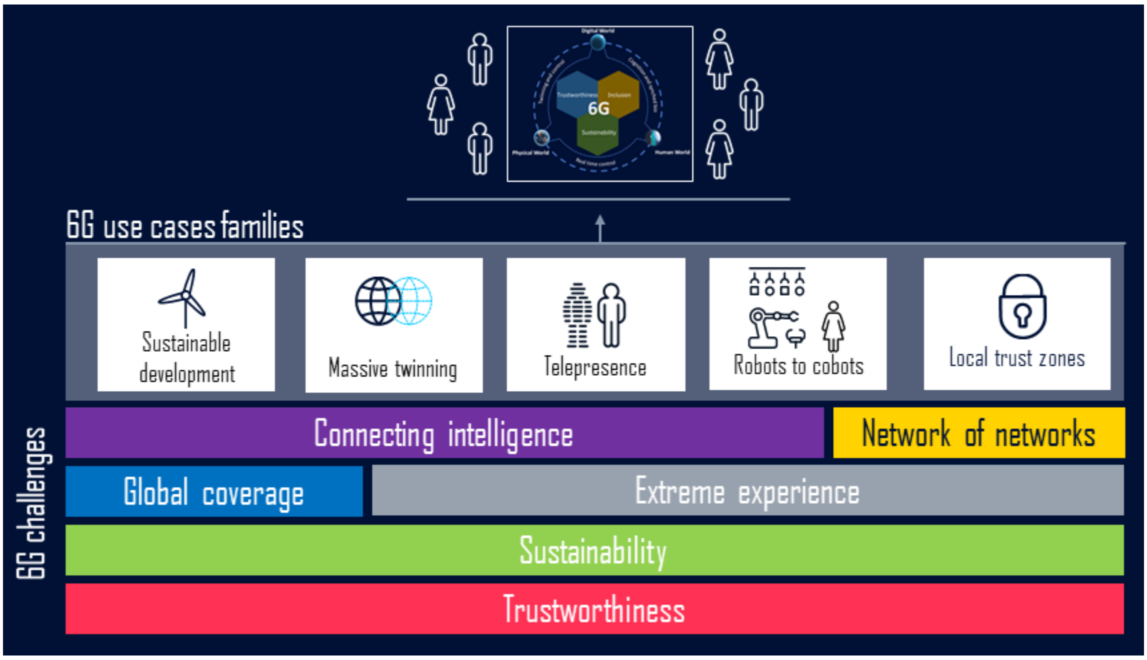

Figure 4-1: ***Overview of Hexa-X use case families***

4.2.2 Sustainable development

The development of the 6G system heralds applications that go far beyond the user- and vertical-centric applications of current and former generations. To address the growing societal concerns of the sustainability of our environment and society, the 6G system will be very well suited to provide a meaningful impact, for example, by providing solutions contributing to meet UN SDGs or helping verticals to reduce their environmental impact. The core values of Hexa-X are trustworthiness, digital inclusion and sustainability. Naturally, these should penetrate through all design and development towards 6G and should be fundamental aspects of all use cases. Especially use cases contributing to dematerialization (telepresence, e-health for all, merged reality game/work), efficient resource usage (flexible manufacturing, AI partner), and optimizations (energy-optimized services) will have substantial beneficial impact towards these core values. However, enablers for sustainability (accounting for digital inclusion) also form a group of use cases of its own, focusing on sustainable development of society.

Sustainability is explicably the foremost research challenge addressed by this use case family, both in terms of environmental sustainability as well as sustainable development of human societies. However, in order to fulfil the UN SDGs, the use case family will encompass all the other research challenges to make the sustainable development come to realization. The extreme performance and global service coverage will be needed to empower the underserved and bridge the digital divide virtual-realistic remote experiences as well as provide means to monitor and counter-act current and impending environmental challenges. Connected intelligence and network of networks will enable operations to be optimized for sustainable performance. Naturally, any system addressing the societal and environmental challenges has to be trustworthy at its core in order to foster widespread confidence in their operation and execution.

4.2.2.1 E-health for all

With trustworthy Mobile Broadband (MBB) connections to medicine expertise, basic e-health services can be delivered anywhere. Connectivity can be complemented by local analysis of samples, etc. with dedicated devices, and availability of expertise can be extended with AI agents giving first-line support. Local mobile e-health hubs can provide last-mile connectivity in areas with infrastructure challenges.

Providing virtual doctor visits to all who need it would be an enormous health benefit, requiring a full expansion of cellular network coverage capable of supporting these services. Reaching everyone in the world in a cost-effective way, and reaching areas where deployment of fiber is not an option (remote islands, rural areas, politically unstable regions) is a meaningful challenge for 6G networks. Sensitive medical data would need to be routed, stored, and processed throughout a network that may consist of multiple hops and access types, and service availability needs to be assured with affordable solutions.

3GPP Release 17 is already moving to this direction with NTNs, as documented in [38.821], for example, along with other satellite communication systems. In 6G we foresee that a tight integration between different topologies will allow for cost-efficient deployments and operations, even to underserved regions, which is currently cost-prohibitive.

4.2.2.2 Institutional coverage

The ultimate goal must be to include all communities with high-grade wireless services – this is true digital inclusion for networks. A more realistic goal is perhaps to make sure that schools, hospitals, etc. around the world can have access to full 6G services, even in developing countries and remote rural areas of developed countries. This goes far beyond video services and includes immersive and precise communication such as telepresence, remote virtual education and medicine. In many areas, deployment of fiber communication may be cost prohibitive, for example, due to long distances in remote areas or islands, or because of inaccessible areas due to political instabilities. By expanding and further improving the deployment and performance of 5G Fixed Wireless Access (FWA), for example, Release 16 integrated access/backhaul (IAB) features and Release 17 NTN features, backhaul based on 6G can be provided to dedicated localities that will act as full-6G digital oases. These key societal institutions connected to 6G services can spread connectivity locally, providing benefits for local companies and infrastructure, and make sure that society is included in the digital development.

3GPP Release 17 is already moving to this direction with IAB as documented, for example in [38.174]. In 6G, we foresee that the wireless backhaul capacity will be enhanced by orders of magnitude, enabling cost-efficient provision of 6G services even to remote areas that are currently cost prohibitive.

4.2.2.3 Earth monitor

By providing ubiquitous bio-friendly energy-harvesting sensors that can easily be deployed anywhere with cost-effective connectivity via, for example, NTN, long-range terrestrial or local mesh networks, a deluge of sensor data can provide near-real-time monitoring of system-critical environmental aspects such as weather, climate change, or biodiversity. Sampling of key data is made possible also in truly remote areas, far from infrastructure. This global telemetry system can be used to improve weather/climate models, provide surveillance and monitoring of environmental status and enable early warning systems for natural disasters such as flooding or landslides, or protect threatened ecosystems like endangered species from illegal logging and poaching.

Even though 3GPP Release 17 is already moving towards NTN, as documented, for example, in [38.821], this use case would require zero-energy and (near) zero-cost biodegradable devices that can effectively communicate with NTNs with very limited power.

4.2.2.4 Autonomous supply chains

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. With global end-to-end lifecycle tracking of goods from production, shipping, distribution, usage and recycling, a 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.

This use case builds on the work done with Narrowband Internet of Things and New Radio Reduced Capability with NTNs and integration of AI/ML. This will require a global system of systems, integrating different technologies into a unified, transparent, and cost-efficient access, which can orchestrate an optimal supply chain end-to-end, while also locally adjusting to any dynamic variations using the currently most appropriate connectivity solution. The system will also monitor the current statuses of businesses and factories in order to predict whenever something needs to be sourced, from where, what optimal and alternative delivery routes are available and to provide even the last-mile delivery. At every step of the way, the location and status of the goods should be monitored in order to facilitate a dynamic and responsive supply chain.

4.2.3 Massive twinning

Massive twinning, i.e., the application of the more fundamental Digital Twin (DT) concept in a wide set of use cases, will gain importance. Massive twinning is designed to lead us towards a full digital representation of our environment, extending the use in production/manufacturing (as it has started today), but also, for example, in the management of our environment, in transportation, logistics, entertainment, social interactions, digital health, defense and public safety.

Twinning is essential in various use cases. A DT is a virtualized model and real-time representation of an asset in the physical world, i.e., a representation within the digital domain, of the asset's structure, role and behavior. Some example areas that are addressed in the remaining part of this subsection are manufacturing (so as to start discussing the progress from the situation of today), the drastic enhancement of the liveability of our cities, the enhancement of the productivity for addressing the "towards zero-hunger" goal, while maximizing the sustainability and the transformation of sectors like health or security. From the discussion it will be shown that such areas will need the transfer of vast information volumes, low delays, high reliability, and capacity levels that will be pushing the current boundaries. Things will continue to evolve and be disrupted. More capacity will be needed (for example, for massive twinning), along with higher bit rates, and improvements in efficiency, reliability and security. Solutions should be characterized by sustainability, power trustworthiness, and most often be suitable for global coverage.

In all cases a fully synchronized and accurate digital representation of the physical and biological worlds is key. This is costly in resources, as it requires precise representations of the physical world, enhanced means for generating insights and predictions, as well as for experimenting with "what-if" scenarios; furthermore, means to impact the environment are imperative. All these need the transfer of vast volumes of data, extreme performance (capacity, bit rates, low latency, compute power) and reliability, as well as sustainability, and also trustworthiness, at unprecedented levels. High-resolution and interactive 4D (spatio-temporal) mapping is needed, in conjunction with means to influence the physical world. High-resolution indoor and outdoor mapping will drive use case scenarios of dynamic DTs and virtual worlds in conjunction with real-time, multi-sensory mapping and rendering, movement prediction and real-time analytics. The availability of both the virtual and physical worlds will allow mapping and analysis of data and monitoring of systems to predict performance and operational issues to minimize downtime (predictive maintenance), and improve contextual awareness.

4.2.3.1 Digital Twins for manufacturing

The use of DTs will continue to grow in industrial/production environments, leading to Massive Twinnning. It will enable us to go beyond the current levels of agility of production, enabling more efficient interaction of production means to encompass a larger extent of the respective processes, and also to achieve the transfer of massive volumes of data, and, often, extreme performance and reliability. In the realm of production and logistics, DTs can be used for many beneficial applications. For instance, the following sub-cases can be identified:

(a) Managing infrastructure resources. The operator of the production facility is trying various scenarios through the DT's "what-if" capability. The scenarios are supported through real-time interaction with the physical world. The operator decides to apply a certain configuration; it is applied with speed and reliability. A critical situation may also arise. The DT forms an accurate picture of the situation (based on advanced reasoning, ML/prediction mechanisms, etc., in conjunction with more traditional polling, alarm functionality), mitigation actions are found by the DT and are enforced at the highest performance levels and with the utmost security.

(b) New products need to be designed and automatically be linked to their DT. New products are designed, and then tested in a virtual environment (even today up to a point); the DT of the planned product is created and is tested in the digital world. Only when that equipment performs to exact specifications in the digital work environment, the physical manufacturing is allowed to start. Once manufactured, the physical build would be linked to its DT, for example, through sensors and actuators, so that the DT contains all the information that its physical counterpart possesses.

(c) The cooperation among multiple DTs in a flexible production process will also be needed, as it ensures anomalies in the real world are detected and mitigated through reconfigurations of the communication system or dynamic adaptations of the production process, or a combination of both. This means that due to the real-time, safety and privacy requirements of production processes, the respective DTs need to be executed in an environment guaranteeing these properties while ensuring access to all relevant data (production, sensing, communication) required to perform the necessary mitigation steps in case of anomalies or to increase efficiency. This use case is also tightly related to the use case family "From robots to cobots" (see section 4.2.5).

(d) Another practical usage of digital representations is to follow the history through "digital threads": the history of every part of the system can be used to learn, to replace parts, etc.

This use case demands low latency and high reliability, at capacity levels that will be much larger than those envisaged for such services in 5G, due to the growing adoption. Moreover, the highest possible level of efficiency is needed for increasing the chances of commercial success. Therefore, this use case requires the realization of Ultra-Reliable Low-Latency Communications (URLLC) grade services, at high capacity levels, and with the highest possible efficiency. The highest possible levels of trustworthiness will be needed (which are associated to the levels of performance, dependability, security, resource efficiency/cost) to ensure adoption at scale.

4.2.3.2 Management of city flows to optimize liveability

City liveability is a concept that is determined by large parameter sets, which are weighted. The sets correspond to wide application areas, relevant to the city infrastructure (for example,., roads, buildings, networks), the ambience/environment (for example, climate, air quality), healthcare aspects, education and culture issues, the stability/safety, and many others. The effective management of all these factors, on various time scales, opens technical challenges, potential from a societal perspective, and business opportunities. Technical challenges are associated with aspects related to the volume of traffic that needs to be transferred, the associated time scales and reliability, etc. Societal value lies in the potential of perceiving, predicting and managing hazards or other less critical situations. Business opportunities occur for operators and other ICT players, by assisting cities in the accomplishment of their goals. Mapping and planning of smart cities will be another use case scenario for DT technology. A city in the 2030s will be a dynamic system of systems with many constituting elements such as people, infrastructure and events. In conjunction with real-time feedback from the physical world and its associated assets, the DT city model will be a powerful tool for future evolution and planning as well as enhanced and efficient operations of future smart cities. An interactive 4D map can be used to plan utilities management such as public transport, garbage, piping, cabling, buildings, and heating, or to connect the many parts of a factory that can be inspected and steered in detail. By overlaying physical modelling, the 4D map can be used to forecast expected and predicted actions and behaviors of the environment and of other users, follow the history, and to check and control the function of parts. Human and AI operators can explore the rich data and simultaneously modify to manage and schedule activities, effectuating changes and tasks through actuators and controllers in the network. This optimized management of flows can also contribute to the transformation of cities towards sustainable models

This use case requires the transfer of vast amounts of data within certain time limits (from ultra-low latency to vehicles or health, to “near” real-time). This is important for enabling actions that will influence the city operation and enhance its liveability. In parallel, the highest possible levels of sustainability are called for, while trustworthiness is most important and will be demanded by citizens.

4.2.3.3 Digital Twins for zero-hunger and production sustainability

One of the UN SDGs is to end hunger, to achieve food security, while maximizing the sustainability of the production. Massive twinning is a valuable concept in this direction, especially, in the light of the challenges for mankind in our time, for example, higher populations, climate aspects, and need for enhanced efficiencies.

The main challenge is that “remote”, “rural”, “in-sea, close to shore” areas need to be provided with higher capacity and performance than today. This is essential for monitoring in real time the conditions at the level of micro-locations (microclimate, soil conditions), inspecting and developing optimized and targeted plant treatments (including disease combatting), experimenting with various actions or strategies (for example, removal of plants, alternate cultivations, spraying strategies), or enforcing actions, including the control of semi-autonomous ground robots. Human expert knowledge will benefit from the closely synchronized digital representation of the physical world, not only for inspecting, but also for experimenting with actions in the digital realm, and, ultimately, impacting the physical world. Therefore, in this use case, the fully synchronized digital representation is the key to optimize agricultural production through improved management and prevention of threats.

This use case requires the transfer of vast volumes of data, from areas that can be characterized as “underserved”, in terms of offered capacity and coverage. Nevertheless, close synchronization is needed. This will make possible the tackling of important challenges of our time, namely, those on sustainability, global coverage, inclusion and opportunity.

4.2.4 Immersive telepresence for enhanced interactions

This use case family consists in **being present and interacting anytime anywhere, using all senses if so desired**. It enables humans to interact with each other and with the other two worlds, and physical and digital things in these worlds. All human senses can be used exchanging sensory information and even extending the capability of the senses. This is well fitting the Hexa-X vision of a future in which everyday experience is enriched by the seamless unification of the physical, digital, and human worlds achieved through the new network and device technologies.

All the research challenges need to be met in order to provide this use case family. Extreme experience is needed to be able to meet the needed data rates. Low enough latency with high data rates and enough reliability is needed to avoid incomplete experience or even nausea. A network of networks is the basis for the connectivity. Connected intelligence improves the performance. This all needs to be done in a sustainable way and trustworthiness is also a fundamental starting point. Global service coverage enables provisioning of telepresence everywhere. Telepresence will have to be delivered in a sustainable way but can also contribute to sustainability and meeting UN SDGs by reducing the need for travel.

4.2.4.1 Fully merged cyber-physical worlds

Mixed Reality (MR) and holographic telepresence will become the norm for both work and social interaction. Via holographic telepresence it will be possible to make it appear as though one is in a certain location while really being in a different location – for example, appearing to be in the office while actually being in the car. Other example use cases include facilitating collaboration and performing remote home-working beyond office type of work by white-collar workers, improving diagnosis during tele-consultations and enhancing teacher-student interactions in e-learning classes. This can also mean virtual traveling to far-away places and telepresence meetings with friends and family. You would experience the world where your hologram is, through very rich sensing of multiple sorts, synchronized to devices on your body for an enhanced sensory experience.

Users want to communicate with distant persons with a quality of interaction very close to reality. They want a better perception of body language (gesture, intonation, expressions, surrounding sounds, etc.), and also of other senses (for example, touching objects).

MR telepresence allows interaction with both physical and digital objects, which are near or far in physical reality. This experience and use case will be enabled by wearable devices, such as earbuds and devices embedded in our clothing and other novel user interfaces. Humans will carry multiple wearables, working seamlessly with each other, providing natural, intuitive interfaces.

Touchscreen typing will likely become outdated. Gesturing and talking to whatever devices are used to get things done will become the norm. The devices we use will be fully context-aware, and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new human-machine interfaces will make our telepresence interaction intuitive and efficient.

4.2.4.2 Mixed reality co-design

Mixed reality co-design means remote collaboration and "experience before prototyping". This may for example apply to a factory scenario where two people are remotely designing something intricate together with some physical objects and some virtual objects.

A MR reality co-design system will allow designers to cooperatively design innovative virtual products in a virtual-real fusion of worlds. Context awareness as an integral part of the MR co-design process will allow designers to focus on the design itself and its relationship with the external environment. MR co-design will link into new forms of man-machine interaction such as capturing the designer's head or eye movement, emotional state, facial expressions, and body parameters such as heart rate or blood pressure. Such an approach can be subsumed under the term "spatial computing". Moreover, the co-design context can be captured by spatial mapping and imaging technology. In the 2030s, we expect designers' behavior and vital parameters to be included in the co-design process and task.

With the leverage of machine learning and AI, the MR co-design use case will be greatly enhanced. The decomposed and advanced user equipment in conjunction with wearables will transform the next generation of Industrial IoT.

4.2.4.3 Immersive sport event

Current sport simulators utilize motion capture technology to create life-like renderings of real players. With the advent of XR gaming, this will be further expanded to allow 3D rendering of any simulated sports event. With 6G, it will be possible to motion capture actual games in real time to create a DT of the whole game, which can be experienced live from any angle, by hundreds of millions of people worldwide. The majority of viewers would likely be satisfied with a classical overview, determined by professional camera operators and thus, the bulk of the information can be broadcasted single-to-multipoint. However, the 3D rendering also allows end users to experience the game from any angle with a 360° view, for example, following a specific player, watching the game from the ball's point of view. In these cases, the processing would have to take place locally to allow high fidelity rendering of the interesting field of view. AI models could also assist in predicting the near-future motion of the players merging real-time footage with pre-rendered models. The experience could be to watch the game from a virtual bleacher while interacting virtually with your friend while watching the game.

4.2.4.4 Merged reality game/work

Gaming in a public or in a dedicated space is experiencing a shared merged reality with a massive amount of people where the distinction between reality and virtuality has been blurred. Some objects or other players in the game are present in the physical world, others are digitally enhanced with visual, haptic or olfactory sensation while yet others are fully digital but appear to be real. Players in the same game share a common merged experience and exchange synchronized sensory information that is authentic or synthetic. Digital meetings can take place where you participate with a hologram avatar of yourself, making you appear fully present. Tactile and sensory feedback can be delivered to participants, and visual information is immersively experienced through a smart contact lens, for example. Digital co-creation is easily handled in the virtual domain, simplifying remote work and training.

Concerning the four use cases described in this section, 3GPP Release 17 is already moving to this direction, as documented in [26.928] and also addressed via the ongoing 3GPP RAN Rel-17 Study Item, whose outcome will be reported in [38.838]. In 6G the efficient interaction among all the three worlds is of high interest, using all senses in a massive scale.

4.2.5 From robots to cobots

The 6G system provides the technical fabric to go beyond pure command-and-control of individual robots. Instead, it empowers robots to become "cobots" in that they form symbiotic relations among each other to fulfil complex tasks efficiently or better cater to the needs and demands of humans in day-to-day interactions. Trustworthiness and digital inclusion are core values in human-machine and machine-machine interaction. By collaborating and building symbiotic relations, complex tasks can be fulfilled in a sustainable fashion: rather than devising more and more complex machinery and allocating more and more resources, intelligent and flexible utilization of existing capabilities to the benefit of society is at the core of this use case family. This also enables new business models for verticals: with increased flexibility in production and resource utilization and connected intelligence, machinery can perform highly individualized on-demand tasks, enabling lot size one production and fully utilizing novel production methods such as additive manufacturing.

A number of research challenges are targeted with this use case family. *Trustworthiness* is at the core, especially as use cases in this family depend on *connecting intelligence* and coming to joint decisions. This requires flexibility in network topologies and resource allocation, targeting the *network of networks* challenge. Some use cases, for example in the industrial context demand *extreme performance*, for example in terms of latency, dependability and positioning. Sustainability is an underlying challenge, especially when dealing with extreme performance use cases. Having meaningful AI partners and human-machine interaction addresses the challenge of inclusion.

4.2.5.1 Consumer robots

Numerous consumer robots will go beyond the automated vacuum cleaners and lawn mowers that we know today and become an essential part of future living. These may take the form of a swarm of smaller robots that work together to accomplish tasks or autonomous robots that provide convenience. Enabled by 6G, the robots will be, for example, equipped with video cameras streaming to a local compute server for real-time processing as well as equipped with advanced sensing and positioning features for seamless and intuitive interactions among users, robots and environment. Robots will utilize the connected AI capabilities offered by 6G for situation-aware cooperation and collaboration and assistance. Thus, we will see an increase in the number of devices and higher capacity requirements within our home networks, further demanding seamless connectivity across the resulting network of (local) networks. In the big picture, domestic robots will enable the elderly to stay in the comfort of their homes for longer and improve their quality of life.

This use case extends existing 5G functionality into more challenging scenarios with an increased number of devices, increased latency demands, positioning and computational requirements with higher integration needs when it comes to sensing and utilization of AI, as later detailed for the use case enabling service “AI as a Service” (see section 4.2.7.2).

4.2.5.2 AI partners

With the advances in AI and its embedding into 6G systems, AI agents will become more prevalent and ingrained in society, alleviating more and more tasks from humans. However, many tasks will still involve human operators actively interacting with AI partners to jointly solve tasks, not only the AI assisting the human operator, but the AI and human working as equal partners. Instead of relying on dedicated machines or specific autonomous system, the AI agent can be much more general-purpose and act as a partner which autonomously and adaptively interacts with other agents (humans/machines), by interpreting intents and surroundings, performing challenging and risky tasks. This AI agent could be a simple stationary machine in a factory, software controlling the illumination wherever you are by communicating with other AI agents in the vicinity, either in your home, in the office, or in a public space, or it could be a group of drones autonomously collaborating to solve various tasks. This requires trustworthy cyber-physical systems able to smoothly cooperate with groups of humans and intelligent machines with precise action.

This use case focuses on broad integration of AI capabilities in 6G communication systems and their offering as a service to applications, such as broad applicability of AI for cooperation with humans. It relies on use case enabling services w.r.t. AI functionality ("AI as a Service", see section 4.2.7.2).

4.2.5.3 Interacting and cooperative mobile robots

In consumer-oriented use cases with multiple robots as introduced above, machines need to identify others, connect, exchange intent and negotiate action through automated communication. Examples of where robots need to coordinate with each other are, for example, awareness such that your personal butler doesn't step on your robot vacuum cleaner; in construction/building scenarios where different robots need to sync/coordinate their movements of lifting, etc.; Automated Guided Vehicles (AGVs) outdoors that need to avoid collisions; swarms of simpler robots coordinating among themselves to perform tasks through emergent action. In industrial environments, going beyond flexible modular production cells (i.e., specific areas where mobile robots and machines collaborate on a production task), some production tasks can be conducted by collaboration among mobile machinery, for example, robots collaboratively carrying some goods while being mounted on AGVs. Here, in addition to the coordination among the interacting entities, process data among involved entities needs to be exchanged, meeting real-time requirements and requiring synchronization: with (static) machinery when departing from a modular flexible production cell, among collaborating machines while on the move, and when reaching the target production cell for the next process steps. Reliability, functional safety, latency and positioning requirements as well as high-energy performance need to be met during all steps and even if trajectories are blocked or need to be altered.

This use case extends existing 5G functionality into more challenging scenarios with an increased number of devices, increased latency demands and a high share of local communication. It moves central tasks of coordinating interacting entities to the entities themselves. 3GPP Release 17 moves into this direction through capability exposure for time-sensitive communication and Quality of Service (QoS) and a fully distributed configuration model for Time-Sensitive Networking (TSN), for example, as detailed in TR 23.700. Sophisticated coordination among entities relies on use case enabling services related to distributed AI functionality exposed to applications.

4.2.5.4 Flexible manufacturing

With increasing personalization and modularization of production (for example, lot size one production of a single, highly customized product) and flexibility of manufacturing systems (for example, mobile robots) comes the need for powerful wireless communication and localization services as well as flexible, dynamic configuration of communication services in the network. The machinery and associated communication will be configured dynamically for each production task, either by a production system or even in a self-organizing way by direct collaboration among (mobile) production machines. This involves the orchestration of AGVs, as higher flexibility in the production process requires higher flexibility in logistics. Dynamic configuration of real-time communication services is required, potentially initiated by end systems themselves and executed in a distributed fashion. Respective communication resources and capabilities (for example, local compute, direct D2D communication, frequency ranges) need to be assigned through a flexible framework. High availability and functional safety requirements need to be met, and data from the production process needs to stay secure and private.

This use case extends existing industrial 5G functionality in more dense industrial environments with higher flexibility, self-organization capabilities, local processing and direct communication among entities. As stated for “Interactive and cooperative mobile robots use case” (see section 4.2.5.3), 3GPP Release 17 moves into this direction. The use case enabling service “Compute-as-a-Service" as another enabler for this use case details additional requirements for local compute capabilities on constrained devices.

4.2.6 Local trust zones for human & machine

“Mobile” communications are up to today often “cellular” communications. Many use cases, however, require local or private communication capabilities for very sensitive information that are tightly integrated in wide-area networks. Here, network topologies beyond cellular topologies and security concepts beyond classical security architectures are required. Local trust zones protecting individual or machine specific information and independent sub-networks such as body area networks enabling advanced medical diagnosis and therapy or on-board networks of AGVs have to be dynamically and transparently integrated in wide area networks.

The work towards research challenges “Connecting Intelligence”, “Network of Networks”, and “Trustworthiness” will contribute to building communication solutions for these use cases. In all cases, private and often local sub-networks are integrated in the classical cellular networks, trust zones for sensitive information – often under very specific regulation – are implemented, and AI functionality is integrated.

4.2.6.1 Enabling precision healthcare and personalized medical treatment

Today`s medicine typically follows a one-size-fits-all approach, in which disease treatment and prevention strategies are developed for the average person. In contrast to this, 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. In order to understand the environment and lifestyle of persons, 24/7 monitoring of vital parameters for both the healthy and the sick through numerous wearable devices will be useful.

In general, health monitoring, diagnosis and therapy, for example, based on precision medicine, will enable personalized diagnosis and treatment. Here, in-body devices communicate with wearables outside, which in turn can transport the data to the internet. Using topical, implanted, injected or ingested sensors and devices, continuous health monitoring can be performed and adjustive measures can be implemented if needed, such as medicine dispensers. Bodily and sensory reactions like organ malfunction and pain can be represented and analyzed in the digital domain. A 6G tele-medical 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 the access to information of the Cyber-Physical Environment. Application domain-specific regulations have to be considered.

This use case requires the interaction of a local trust zone with the wide area network security, access to information available in other networks under pre-defined filtering rules, and a split of network transport, control and security. From a regulatory perspective, in addition to the difficulties to adjust to regulations of the medical sector, the integration of medical devices in wide area networks is today at least challenging and is disruptive.

4.2.6.2 Sensor infrastructure web

A simple autonomous vehicle (with no or limited sensor capabilities) is moving around the environment, while relying on external third-party sensors as if they were on-board sensors. The vehicle obtains external sensor data or navigation commands through the network with utmost confidence in the reliability, timeliness and confidentiality of the data, and can as well share its own sensor data. This allows aggregation of sensor data across different systems, even to devices lacking their own sensor capabilities.

The network can advertise locally relevant and trusted sensor information that all connected devices, for example, vehicles, can access.

3GPP today does not allow diffusion or sharing of sensor data in predefined local environments and to networks or network parts under external security management. Depending on the implementation, this use case might require the split of network ownership, network control, network transport and network security. Finally, today it is not possible to allow a network to advertise and distribute third-party provided sensor data in well defined local areas.

4.2.6.3 6G IoT micro-networks for smart cities

The expansion of smart cities usages (for example, energy management, traffic control, citizen safety) will entail massive deployment of communicating objects. Administrators of smart cities want to deliver the required coverage for smart city networks with minimized energy consumption and without multiplying base stations. They need self-adaptive networks, relying on objects as relays. These micro networks would manage the flows of information from objects, robots, etc, locally interacting in a complex system.

Network slices and private networks bringing their own network nodes exist in 5G. Here, micro-networks of potential different ownership and with a potentially external security management might share parts of the infrastructure with wide area networks, i.e., a private network with partly owned infrastructure and a private trust policy is integrated in a public network.

4.2.6.4 Infrastructure-less network extensions and embedded networks

At the edge of network coverage, a temporary network coverage extension is required, for example, for providing connectivity between several agriculture vehicles during harvesting campaigns. The connectivity should remain even when the vehicle platoon is leaving the network coverage completely while still in the harvesting campaign.

An industrial vehicle manufacturer has a fleet of its shop-floor vehicles deployed in a factory. While all or some of them are connected to the wide area network, the manufacturer wants to have reliable networking solutions between his vehicles not using the local network, i.e., a local private infrastructure-less network being established. This network might have authorized access to the spectrum of a local non-public network or a public network, thus external network control should be enabled.

D2D solutions exist in LTE and 5G. Direct Mode Operation (DMO) is a typical requirement for Public Protection and Disaster Relief (PPDR). Construction work, agriculture, and tactical services — often operating at the edge of network coverage — regularly ask for coverage extending concepts beyond D2D and autonomous operation of island solutions. Mesh networks, multi-D2D might be options. Temporary security solutions are required. Networking islands of several devices re-joining the cellular networks shall be seamlessly re-integrated. D2D could be seen as a first step, and DMO solutions are known from several standards.

4.2.6.5 Local coverage for temporary usage

PPDR and Program Making and Special Events (PMSE), roadwork and harvesting campaigns benefit from applications as massive video transmissions that often require local networking coverage fulfilling high requirements. When cellular coverage is not available, local, only temporarily deployed networks enabled by drones, high altitude platforms or other means can be used. Automated licencing processes can help to guarantee access to the required spectrum resources.

Today temporary deployments for PPDR and PMSE are already used. However, lowering the costs of the deployment and the administrative burden, for example, by automated licencing, might help this option to become more widely used.

4.2.6.6 Small coverage, low power micro-network in networks for production & manufacturing

A machine manufacturer wants to mutually connect a large population of sensors in his machine using – for reliability reasons – non Industrial, Scientific and Medical spectrum. This can be done with very low-power devices and very limited coverage as an underlay network, potentially with one of the sensors getting the authorization out of the public or non-public network of which the spectrum is used.

This could be seen as a shared spectrum access concept under full control of the incumbent. The incumbent might have the option to disable the spectrum usage by signalling.

4.2.6.7 Automatic security

There will be a massive deployment of wireless cameras as sensors. With advances in AI and machine vision and their capacity to recognize people and objects (or more generally, automatically gather information from images and videos), the camera will become a universal sensor that can be used everywhere. Privacy concerns will be addressed by limiting access to data and anonymizing information. Also, radio and other sensing modalities like acoustics will be used to gather information on the environment. In short, advanced techniques will be used in security-screening procedures to eliminate security lines. A combination of various sensing modalities will be used to screen people as they move through crowded areas rather than only at entrances. Radio sensing will be an essential component of achieving this; supported by the communication systems of the future the network can sense the environment. For example, it could be programmed to automatically detect metallic objects of certain kinds that people or robots may be carrying in a crowded square. The network can sense and identify potential threats.

4.2.7 Use case enabling services

In the initial collection of use cases, some ideas have emerged, that may not be categorized as use cases according to the definition above, but that deserve to be shared to the ecosystem. They can be considered as services useful to address the use cases proposed above and, possibly additional ones.

The services identified and detailed below enable the realization of the use cases described in the previous subsections. For instance, scenarios falling under the massive twinning and robots/ cobots use case families can benefit from the Compute-as-a-Service (CaaS), general-purpose AI-as-a-Service and AI-assisted Vehicle-to-Everything (V2X) concepts, as these use cases may involve resource-constrained devices and may need to be based on data-driven decisions, respectively. In another example, a service dedicated to addressing the challenge of multiservice devices with heterogeneous requirements may be applicable to immersive telepresence scenarios characterized by both extreme data rate and ultra-low-latency requirements. Also importantly, use cases related to sustainable development may benefit from energy-optimized "green" connectivity services and "Internet-of-tags" services aiming to limit the incurred environmental footprint.

Additionally, these services are, in their turn, enabled by key technologies that are building blocks of systems, subsystems and components, and which will be studied in detail in different WPs of Hexa-X. Some of these key technologies are: distributed computing, AI/ML and network intelligence, radio access beyond 100 GHz, as well as an open service-based network architecture. The aim of such architecture will be to provide needed interfaces outside network infrastructure (for example, user devices) entailing network virtualization and disaggregation concepts. Moreover, energy-efficient networking solutions are essential to ensure a sustainable digital world. Each of the services described here is connected to one or more research challenges identified in the Hexa-X 6G vision.

4.2.7.1 Compute-as-a-Service (CaaS) for resource-constrained devices

This service is aimed to be used by resource-constrained devices (static or mobile, IoT, handhelds, etc.) that choose to delegate demanding, resource-intensive processing tasks to a network providing more powerful compute nodes; these service-offering compute nodes can be either onboard other devices or, for example, edge cloud servers at the infrastructure side. A first example is the one of a worker performing equipment maintenance. The worker uses special equipment (glasses, gloves, vests, etc.) useful to capture information (for example, video footage, images, sensory information) of the process. The respective workload for data fusion, sensor data processing, etc. needs to be processed in a reliable and timely fashion; however, the computational/ memory/ storage resources of the special equipment are limited. As an alternative, instead of a human, any kind of small robot (for example, AGV, unmanned aerial vehicle) of limited energy, storage and computational resources can play the role of the maintenance entity. Workload delegation to powerful nodes at the network will be essential for the stability of a closed loop system involving measurement capturing, processing, issuing an actuation policy and implementing it. Another example is the one referring to the collection of data and remote processing for Earth monitoring; examples are small robots/pathfinders/probes and ground stations deployed in forest/arctic areas collecting sensory information or analyzing (air, water, ground, etc.) samples. A third example of the CaaS concept is the one of multi-player gaming, where complex computer games may be processed on computational resources in the network, which will be able to address high computation load requirements and meet low latency requirements for multi-player gaming. The CaaS service tightly relates to the Extreme Experience, Sustainability and Connecting Intelligence research challenges.

This service goes beyond 3GPP Rel-17 specifications on support for Edge Computing in 5G Core network (5GC) (see [23.748]). It also expands beyond the task offloading use case, as documented by [EGM20].

4.2.7.2 AI-as-a-Service (AIaaS)

This service can be consumed by applications instantiated at either user and IoT devices, or at network infrastructure submitting requests for ML-based inferencing decisions to the network (for example, to other devices or to edge cloud hosts with already trained models). A first example relates to inclusiveness of the elderly and people with motion/vision impairments, in which, for example, a person with vision impairments is equipped with wearables including sensors collecting environmental/ surroundings data. These sensory data are exploited to infer and identify objects, street furniture and possible hazards so that the user can be informed in advance and take proactive measures. Such environmental identification via object classification is useful to improve the inclusiveness and quality of life per the UN SDGs. A second example is the one of in-advance QoS predictions based on a plurality of data (for example, from the Uu and PC5 interfaces but also from vehicle sensory (RADAR, LiDAR) information); a driver/ machine (for example, used for tele-operated driving) planning to perform a journey would like to be informed of any V2X service degradations along the planned route. The reasoning of such needed notifications is the possible prioritization or postponing of software over-the-air downloads, the activation/de-activation of autonomous driving functionalities and features, etc. Computational intelligence is needed, in this case, which can be provided by an ML-based prediction function instantiated anywhere at the network. An additional example is the one of AI-based high-resolution image/video processing in which a user is able to take a high-resolution image or video of a large crowd such as an audience in a soccer stadium. A remote AI agent may be used to identify specific persons or objects, including friends, family, an unattended child, etc. The AIaaS service primarily relates to the Connecting Intelligence research challenge.

On top of 3GPP Rel-17 specifications (e.g., [29.520] on Network Data Analytics Services), where, the consumer of the service provided by the Network Data Analytics Function (NWDAF) is a Network Function (including an Application Function implying also a third part application), per AIaaS concept, the service producer can be any AI agent reachable, as part of the network, even instantiated at the UE side (in case the latter one is of needed inferencing capability).

4.2.7.3 Flexible device type change service

This service aims to be consumed by devices to effectively and flexibly change their device type, for example, from a consumer device (like today's smartphone) to an industrial IoT device to a V2X device. As an exemplary user scenario, we consider the case that a user owns a consumer device (such as today's smartphone) that is typically used for voice/data communication in a non-safety-related context. When the user is entering an area where V2X communication is being used (for example, on a road, on a side-walk close to a road), the user device changes its purpose (and, therefore, its type) and will enable safety-related communication; a Vulnerable Road User (VRU), such as a pedestrian, will be warned in case of danger, a vehicle will have access to Vehicle-to-Network (V2N) services through the smartphone, etc. This requires that a device can flexibly change its type and configuration depending on the currently active service needs. This service is mainly relevant to the Network of Networks and Trustworthiness research challenges.

This service goes beyond 5G NR standardization, as device assignment to a network slice is static in 5G; for example, a consumer device is assigned once to a specific network slice. The challenge for B5G/6G systems lies in the extremity of performance requirements for new applications, for the addressment of which 5G solutions may be insufficient. Flexible device type change may evolve today's network slicing concept in 5G to the one of "device slicing".

4.2.7.4 Energy-optimized services

Users want to be given the choice of consuming "green" ICT services, with reduced environmental impact with respect to traditional services, in a holistic manner, considering not only the applications, material, etc. but also the technology and the E2E network design. As environmentally friendly users, they will be invited to consider possible trade-offs between performance, cost and environmental impact, enabling them to monitor the overall environmental impact of their products/services. Such services aim to mainly address the Sustainability and Global Service Coverage research challenges.

This service considers the energy consumption end-to-end, considering the environmental impact of all the elements involved in the service: application, network, terminal, etc. These energy-optimized services will require not only energy-optimized networks, but also energy-optimized applications, appropriate upcycling of materials, etc. Providing a holistic view will require new indicators of the environmental impact and an aggregation of these indicators to reach a global view.

4.2.7.5 Internet-of-Tags

Tags will be present everywhere to facilitate everyday life. The tags will enable multiple operations: collecting information through tracking of label-tags and monitoring and acting on the environment through smarter tags, with sensing or actuating capabilities in addition to communication capabilities. For instance, tracking merchandise with basic label-tags can improve logistics; tags capable of sensing temperature/light, etc. can be monitored to optimize energy consumption for heating/lighting, etc.; tags that are activated with the manual pressure of a button can be used to switch on/off light or heating. To limit the impact on the environment, tags will not be powered but will rely on energy harvesting to enable communication between tags or between tags and network, sensing, actuating, processing of the data collected. Energy harvesting will be performed through re-using ambient or renewable energy, for example, using surrounding (already existing) or dedicated RF waves, solar energy, wind, vibration, mechanical push. Finally, "zero-environmental-cost" tags can be considered, utilizing for example printed electronics to enable ubiquitous tags, while still ensuring sustainable handling at end-of-life of tags (e.g., bio-degradable).

This service generalizes and extends the use of tags and the concept of energy harvesting, relying on multiple possible sources (RF waves, solar, …), going into massive deployment. It also includes communications of the tags with the network and will enable monitoring and controlling the environment.

4.2.7.6 Security as a service for other networks

Any kind of device being connected to a public or non-public 6G network with large coverage uses the connectivity for selected device management and in particular security functions only and the transport from other networks or even wireline.

This option is already used today, but requires full management plane. A super light version with only selected management functionality might open up new business cases for MNOs as Trust-Anchor Provider, Trusted Assessment Provider or Device Manager. Network efficiency from the cost, power consumption, and management complexity points of view need to be further enhanced beyond current 5G approaches.

4.2.7.7 AI-assisted Vehicle-to-Everything (V2X)

Safety and security are of high importance for any transport system, especially road transport due to the prevalence of accidents. Several initiatives have been conducted to promote rules, technical standards and awareness campaigns to decrease the number of fatalities caused by road accidents, (refer to the European Commission' Road Safety website [ERS21]). Moreover, studies and trials proved that AI can be exploited for making roads safer, as reported in [FSN19] and [MSN19]. This motivates the need to further explore the potentiality of the AI algorithms for enhanced automotive services provided by future 6G networks. The novel AI algorithms, applied to the big data collection gathered by sensors (in and outside of the cars) as well as radio stations in the operators' networks, will allow dynamic shaping, monitoring and suggesting actions/recommendations to connected vehicles' drivers — or, potentially, to directly control the automated vehicles in order to reduce the traffic caused by them. This will have an important societal impact allowing a safety improvement for drivers and passengers as well as minimizing traffic congestion. With respect to C-V2X technologies already developed and based on LTE and NR, the processing of the massive amount of data gathered through the automotive services offered by communications networks is far to be managed properly and this creates room for the introduction of AI-based algorithms to dynamically control and shape the traffic, generating a digital replica of the real traffic scenario. The real-time creation and adaptation of such digital replica encompassing an entire urban area is very challenging and requires network capabilities not currently available; in addition, the intertwining of digital and physical worlds, as foreseen in Hexa-X, will improve not only safety but also the mobility's sustainability in a human-centric fashion. Latency and location accuracy are essential for these AI algorithms in order to control real-time-like the type, the evolution and the shaping of the traffic in large scenarios like today's cities.

4.2.8 Hexa-X use cases: Summary

The project identified five main use case families, and an additional family of use-case-enabling services. This initial set of use cases, summarized in Figure 4-2, is a starting point for the project, and will be enriched, accounting for developments in the ecosystem, new findings in the project and from other projects.

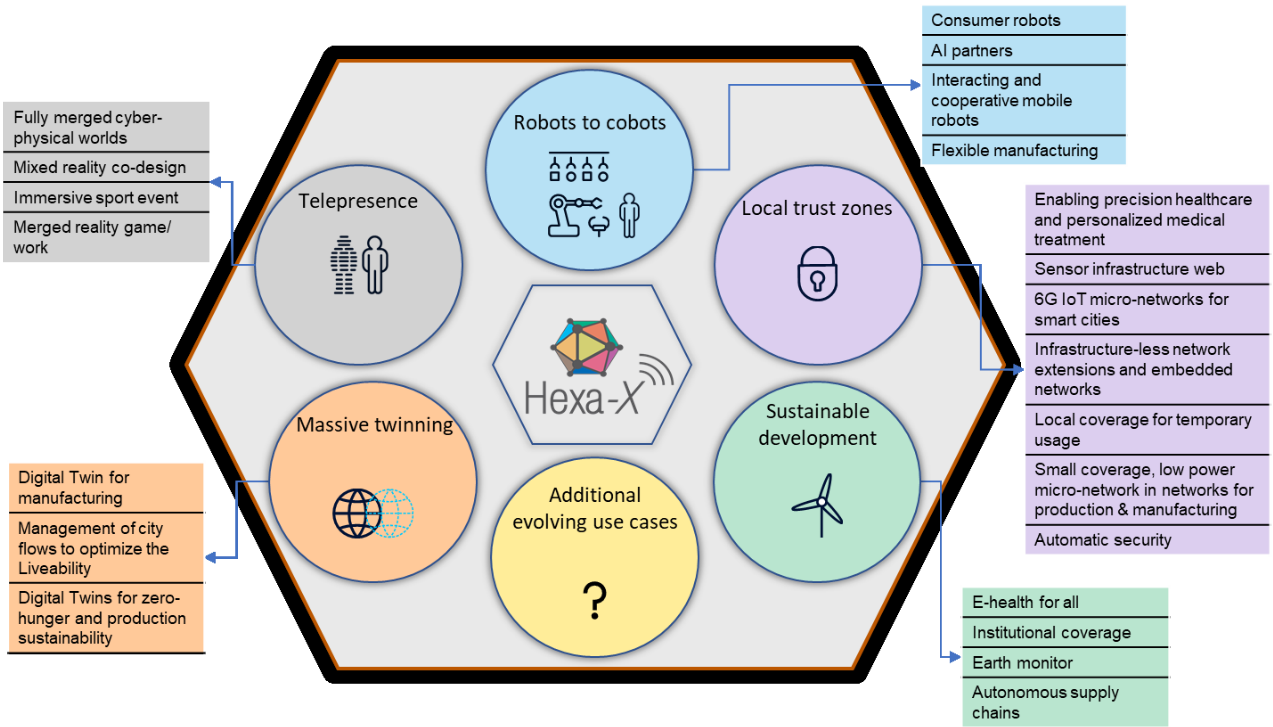

Figure 4-2: ***Summary of Hexa-X use case families and use cases***

5 Key value and performance indicators (KVI/KPI)

In this chapter, the reasoning behind introducing Key Value Indicators (KVIs) and their role in assessing the effect of the key enabling technologies is detailed. State of the Art on performance and value indicators is reported and research challenges for Hexa-X are outlined.

5.1 KVI and KPI mission statement

Hexa-X recognizes the necessity to expand the fundamental network design paradigm from performance-oriented to both performance- and value-oriented in order to fully embrace the 6G vision. Here, *value* entails intangible yet important human and societal needs such as sustainability, trustworthiness, and inclusion. This leads to a new class of evaluation criteria, i.e., Key Value Indicators (KVIs) that must be understood, developed, and adopted in the network design towards 6G. Figure 5-1 illustrates the concept of KVIs. The KVIs mentioned in the top right address the UN sustainable development goals, with measures for sustainability, security, inclusiveness, and trustworthiness. In addition, the value of new capabilities enabled with 6G needs to be captured; this includes integrated sensing, embedded devices, local compute integration and integrated intelligence, as illustrated in the lower right. While some KVIs are motivated by the use cases as discussed in the previous section, others are directly motivated by technology: this includes, for example, the integrated sensing capabilities of a 6G system.

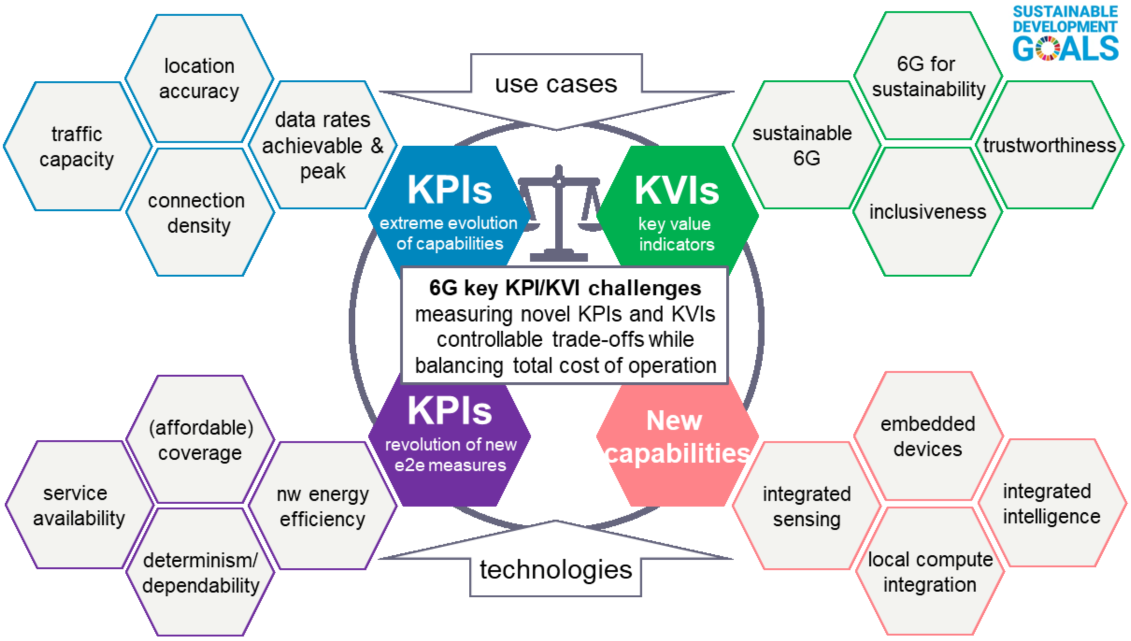

Figure 5-1: ***Clustering of KPIs and KVIs***

In addition to the novel concept of KVIs, KPIs and performance goals need to go beyond what 5G can do to address new use cases discussed in the previous chapter. This includes increasing peak data rates and data rates achievable at the cell edge, density of connections, traffic capacity, and location accuracy to a substantial extent. For some performance goals, e.g., dependability and determinism, service availability, affordable coverage, and network energy efficiency, the focus will shift more towards new end-to-end KPIs in specific use cases, and extreme performance in terms of data rates might be confined to specific scenarios rather than being a general, system-wide goal. Depending on the use case, novel KPIs for this end-to-end perspective will be defined.

In addition, the relation between the fulfillment of KPIs and the associated total cost of operation becomes increasingly complex, given the number of stakeholders involved and the potential of networked intelligence and service-oriented ownership and business models on local and global scale.

The *evolution* of KPIs and the *revolution* of new end-to-end KPIs and new KVIs in 6G is tackled top-down on a use-case basis and bottom-up from the viewpoint of individual technical enablers in Hexa-X (WP 2-7), as outlined in the following sections.

5.2 State of the art on 6G KPIs and KVIs

In [ACI20], an open ecosystem for Operational Technology (OT) networks in industrial environments is motivated: Openness relates to interoperability with other hardware used in OT networks, compatibility with commonly used technology like Time-Sensitive Networking (TSN), and sustainable integration with the existing installed base. To quantify the required and achieved level of openness in this regard, novel KVIs are required. Local and remote use cases are distinguished in [ACI20], with aspects such as isolation for automation networks and machine safety, but also regarding data privacy (for example, data is not allowed to leave the premises). Here, requirements originating from the automation application such as packet loss rates below $5*10^{-7}$ and no consecutive packet loss motivate the need for novel cross-layer dependability metrics. Such dependability metrics need to take application characteristics such as recovery times into account. Additionally, reliable time synchronization within microseconds is a key requirement for automation networks. Regarding security, the potential for integration into existing security architectures is a requirement that needs to be supported.

In [ZY20], the authors state that KVIs can be broadly clustered into (i) growth and (ii) sustainability and efficiency domains. They propose to measure 6G impact for growth by measuring economic growth and new value chain, ecosystem and business models. Sustainability and efficiency objectives should utilize the following value indicators: total cost of ownership (TCO), time-to-market (TTM) and flexibility, open collaboration, security, privacy and trust, energy consumption, serving the underserved, megacity impact, and public protection and disaster recovery (PPDR).

According to [ZY20], 6G performance indicators with very high impact on economic growth include the expected high number of 6G private and dedicated networks as well as the number of devices including sensors. Furthermore, network slicing and network of networks automation as well as sensing will show high impact on economic growth. Ecosystemic business models and platform transformation is found to be a key value driver enabled by very high number of private and dedicated networks and 6G flexibility, automation and granular slice instantiation. Besides impact on scalability and replicability and therefore growth, sustainability and efficiency targets deserve attention. Six performance indicators were identified with likely very high impact on efficiency and sustainability targets: new business models will be greatly boosted by a fast growing number of private networks; TCO will be significantly reduced by zero energy devices and by flexible automation of network of networks; flexibility and automation and capability to instantiate thousands of network slices will also have positive impact on TTM. Open collaboration can be considered both a means and a goal – flexibility as required to build network of networks architecture and technology will leverage vehicles of openness including SDOs, open source and white box. Key enabler to help reduce energy consumption may well come from making trillions of devices and sensors consuming zero energy. The key performance indicator with single-most important impact on driving smart megacity transformation may well be density of devices per square-kilometer, whereas coverage and non-terrestrial coverage will help deliver on the objective of serving the underserved.

In the white paper [Eri20a], the vision of *Ever-present Intelligent Communication* is discussed based on the drivers of trustworthiness, sustainability, extreme applications, and simplified life. Looking at the use cases that are expected to come from these drivers and to appear in the 2030 timeframe, [Eri20a] sees two directions of expansion going from 5G to 6G; the first being to continue improving the current set of capabilities pointing at targeting quantitative parameters like capacity, data rates, E2E latency, and connecting massive amounts of devices; while the second being to aim at new capability dimensions with more qualitative nature such as security, local compute integration, service availability, and positioning and sensing capacities. In between those two sets of capabilities, one can place energy efficiency and coverage, which have been targeted by previous generations of mobile networks but where the interpretation and ambitions should be scaled up to cover the whole network system and the whole world, respectively. Important is also to consider a sustainable level of total cost of ownership or operations as a basic ambition.

The white paper [NTT20] presents 6G as focused around *Cyber-physical fusion*. The main areas for 6G to address are solving social problems, communication between humans and things, expansion of communication environment, and sophistication of cyber-physical fusion. The 5G use case areas of mMTC, URLLC, and eMBB will evolve into new combinations with more specific use cases and extreme requirements. The capabilities needed for delivering this around 2030 are mainly seen as expansions of those of 5G, aiming at going further in the directions of data rate, capacity, coverage, low energy consumption, low cost, low latency, high reliability, and massive connectivity, but with the last two pointing in partly new directions of security/privacy and positioning/sensing.

The white paper [Sam20] envisions 6G to *bring the next hyper-connected experience to every corner of life*, with a focus on the megatrends of connected machines, AI, openness, and social goals. The new services brought by 6G will revolve around the key areas of immersive XR, mobile holograms, and digital replicas, which will require improvements in the 5G KPIs of data rate, energy efficiency, spectral efficiency, latency, connection density, reliability; but also an expansion into the new capabilities of communication and computing convergence, and new requirements in the domain of security.

The first Finnish 6G Flagship white paper [LL19] addresses key drivers and research challenges for 6G. Many of the technology-driven KPIs developed for current and emerging 5G technologies (e.g., peak data rate, ultra-reliability, traffic increase) are seen valid for 6G with respective increments in capability. However, they should be critically reviewed and new KPIs need to be seriously considered. Initial 6G KPIs have been divided into *technology and productivity driven KPIs* and *sustainability and society driven KPIs*. The former can be further categorized to latency, jitter, link budget, extended range/coverage, 3D-mapping fidelity, existing tuned 5G KPIs, position accuracy and update rate, cost, and energy related KPIs. The latter covers inclusion of vertical players in definition of requirements and standardization, transparency KPIs (e.g., related to AI), privacy/security/trust KPIs, global use case-oriented APIs, UN SDG inspired KPIs, open source everything, and ethics KPIs.

The next round of the Finnish 6G Flagship white papers [6GC20] go deeper in the following thematic areas: 6G drivers and the UN SDGs, business of 6G, validation and trials for verticals towards the 2030's, connectivity for remote areas, networking, machine learning in 6G wireless communication networks, edge intelligence, research challenges for trust, security and privacy, broadband connectivity in 6G, critical and massive machine type communication towards 6G, and localization and sensing [6GC20]. Performance and value indicators are considered more closely from each topic's own perspective. As an example, [Pou20] compares industry mMTC, industry eURLLC, mobility, eHealth, energy, finance, public safety, and agribusiness verticals and their respective KPI and KVI requirements. It is noteworthy that KPI assessment is highly use case dependent with a large variation between verticals. Also, setting numerical values for KVIs is hard and the assessment of them is only indicative at first. The use case dependency of KPIs is also stressed in recent technical reports by the ITU on representative use cases and their requirements [ITU20a, ITU20b].

In [Ora20], the importance of defining societal requirement is stressed, in addition to the "traditional" performance KPIs (data rates, capacity, latency, reliability, connection density, etc.). Defining 6G should build upon the lessons learnt from 5G deployment, and more specifically the real adoption of extreme requirements, before defining new performance requirements. In order to ensure societal relevance and acceptance, the needs and expectations from end users must be accounted for, through the formulation of societal requirements, associated with target values for 6G. These societal requirements should be considered with equal importance as performance requirements, and can include energy efficiency, aiming at gains as high as capacity gains with respect to 5G, very low end-to-end environmental impact, higher EMF-awareness, higher digital inclusion (with improved affordability, coverage of low density areas), higher security and much higher resilience.

5.3 Hexa-X challenges and contributions regarding KVIs and KPIs

The main challenges with respect to KVIs and KPIs are illustrated in Figure 5-1: being able to measure novel KPIs and KVIs, and being able to provide controllable trade-offs while balancing total cost of operation. In the following, we provide a more detailed discussion on the challenges ahead and on the planned contributions in Hexa-X.

When developing towards 6G we should move in multiple dimensions: expanding the set of capabilities, aiming at key values, and redefining as well as advancing on an existing set of capabilities. The capabilities in turn can be mapped to measurable KPIs, whereas key values are mapped to KVI (see 6.3.4).

5.3.1 Advancing on existing KPIs

Bringing 6G forward, it remains important to advance on the fundamental capabilities of delivering extreme data rates, capacity, location accuracy, and connection density, which will continue to serve both the existing use cases with better performance and reliability as well as novel use cases relying on similar capabilities.

Data rate

Peak data rates are important in certain scenarios for extremely demanding services, while in a general scenario, it is more important to consider the user experienced data rate. Both should take a significant step from the 5G levels. For instance, fixed wireless access (FWA) and integrated access and backhaul (IAB), are expected to operate at peak data rates, as the stationary nature of the use cases can enable full utilization of line-of-sight communication without restrictive battery operation, whereas handheld or other devices will be highly mobile with stringent power consumption restrictions. In all scenarios, it will be imperative that the performance delivered suffices to fulfil the service requirements of the applications in use.

Capacity

Compared to 5G networks, the total traffic capacity per area should increase several times to support demanding services with a multitude of concurrent users. As both, the peak and average date rate and the connection density are expected to rise significantly for addressing extremely demanding multi-user use cases, the traffic capacity must be extended for all, the access, transport, and core networks.

Localization

Precision and accuracy in positioning services should by far exceed that achievable in 5G and GNSS. Although current systems allow for meter precision in positioning, e.g. for map services or localization for emergency calls, 6G will enable applications that rely on much stricter positioning accuracy.

Connection density

The number of served/connected devices in an area should be much higher than supported in 5G to enable embedded devices everywhere. With the advent of near zero-cost, near zero-energy devices, the marginal cost of introducing additional devices will plummet, adding additional requirements on the network to support the connections while still maintaining service for the high-performance devices.

5.3.2 Redefinition of existing KPIs

A set of capabilities have been in focus for previous generations of communication networks, but should now be considered in a comprehensive, end-to-end perspective. By shifting focus from enhancing the best-case peak performance to improving the worst-case guaranteed performance a new slate of critical services can be enabled.

Service availability

As applications and services become even further ingrained in our societies, the expectations of ubiquitous and interminable service availability will rise. Important aspects are here: the fraction of device population for which a service can be delivered with a certain availability; minimum service interruption due to events or mobility; and network survivability over time.

Deterministic services

It should be possible to deliver guarantees for: achievable data rate; maximum end-to-end service latency; and end-to-end packet reliability in order to enable, e.g., use cases from the automation domain or in human-machine interaction (c.f. use cases in Section 4.2.5).

Coverage

The key aspects to consider here are: fraction of global surface covered; fraction of population covered; total cost of coverage per area; and traffic volume while providing 6G performance and services.

Network energy efficiency

The end-to-end perspective should be considered for energy consumption. Relevant parameters are: total energy per delivered bit; signaling overhead; total energy consumption per service area; and total resource consumption per delivered bit.

5.3.3 New capabilities leading to new KPIs

6G is targeted to introduce several new capabilities which will broaden the utility of the communication networks. These capabilities will both enhance the performance of traditional services as well as enable paradigm-shifting new services. For this expanded set of capabilities there should be clear definitions and targets both in terms of intrinsic performance of the capabilities as well as the enabling effect to other features. These performances will be developed further during the progress of the project to capture the improved understanding and align it across technical work packages.

Integrated sensing

The intrinsic properties of localization and sensing rely on traditional sensing parameters such as relative precision in position and velocity; angular resolution; accuracy in parameter estimation; and convergence time of estimation. However, the system co-design for both, communications and sensing purposes, allows for enhanced performance in terms of coverage and throughput, as well as service interruption during mobility.

Local compute integration

The intrinsic properties of local compute integration will be key parameters such as RTT to compute and storage as well as time-to-market to introduce additional compute capabilities. However, the integration of local compute capabilities is done to enhance other features which could be measured with use-case specific KPIs, for example, Quality of Immersion.

Integrated intelligence

Integration of AI/ML encompasses both utilization of AI/ML for optimization of network operations in a pervasive way (for example, AI/ML-defined air interface framework), as well as optimization of network operations for optimal performance of AI/ML features. For the utilization of AI/ML to enhance network features, the relevant parameters will be e.g. convergence time; enhancements over existing analytical or heuristic features; fault rate; and added energy consumption. For the optimization of the network to facilitate AI/ML features, the relevant parameters will rather be flexibility to adjust parameters; time-to-market of new features.

Embedded devices

If a wireless device is to be embeddable anywhere, access to an external power source cannot be taken for granted. In addition, the placement of the devices may prevent or prohibit the usage of batteries as a power source. Therefore, these devices may rely on energy-harvesting of some form and to keep down cost, the devices may be produced using printable electronics.

Key aspects to consider for embeddable devices are: energy consumption; form factor; cost; time between maintenance occasions; total resource consumption and end-of-life handling.

5.3.4 Challenges when capturing societal needs with KVIs

There are key values and defining characteristics that will drive 6G, as outlined in the project vision in Section 3.2. These include sustainability, inclusion, and trustworthiness.

It is generally much harder to quantify values than technical capabilities. If it appears to be overwhelming to measure a certain value, it is always possible to resort to softer indicators in the value evaluation. This could mean, for example, ordering values in their respective significance from the application and use case point of view or recognizing emerging trends and taking those into account while elaborating KVIs. In addition, the perceived performance is more or less universal, the perceived value is heavily rendered by background, culture and even ideology of individuals as well as operating locations, regulatory environment and stakeholder structure of enterprise. Consequently, an open and inclusive framework is required to be able to adapt to different perceptions and backgrounds when quantifying and weighing different KVIs.

Being able to include individual perceived value in a flexible framework also addresses ethical issues when it comes to the right of being included (and, equally important: the right not to be included) in certain new technical abilities of a system. This relates, for example, to localization and mapping, but also to utilization of data in AI-based algorithms.

Regarding sustainability, even if the current contribution of ICT domain to the total carbon footprint of the society is limited (between 1.4% [EriTelia18] and 3.7% [Shi19]), the increase of digital usages will require densification of networks capacity adaptation and more devices and IoT manufacturing leading to an increase of this ratio (from 2% in France in 2019 to 6.7% in 2040 [Sen19]) if no drastic change in the behaviors and policies is applied; this being said it is expected that the ICT sector could reduce its environmental footprint by 45% between 2015 and 2030, assuming the 1.5°C trajectory has to be met [ITU20a]. Interesting to note that in 2015 the power consumption of devices represents more than 50% of the ICT power consumption (roughly 20% of the ICT power consumption comes from devices manufacturing and supply chain). This means that for the "usage" phase, devices and networks are more or less equivalent. However, the "manufacturing" part of ICT total carbon footprint is a little bit more than 15%, what requires to focus part of the effort on improvement of life cycle of the networks (including equipment and devices, their lifetime, their recycling, etc.).

ICT sector spent more than a decade improving its efficiency thanks to hardware optimization, material novelties and sleep modes innovations. This lead probably to maintain the IT and network sector environmental impact under control while the traffic has increased by +40 to 100% per year in the same period. Trends in Europe and all over the world are now towards ecological transition of all the sectors (agriculture, education, transport, industry…) and ICT has a crucial role to play to achieve this challenge.In order for the user of digital services to be informed and aware of the impact of his digital behavior to the environment, it is of interest to define and provide him/her with a Green Barometer, what is actually promoted by the French regulator ARCEP [Arc20a].

Once this barometer and its parameters are known (end of 2020), Hexa-X can build on top of it and could derive recommendations to the end user in order for him/her to act in a more sustainable manner. This not only affects end users, but all stakeholders along the value chain, including service offerings running on the 6G system.

5.3.5 Challenges with measurability and increasing complexity

The KPIs and KVIs (and their target values) may lead to contradictory actions, e.g., providing a global coverage may require the deployment of additional infrastructure, e.g., base stations, and then lead to an increase in power consumption and carbon footprint. So the 6G technology needs to provide built-in capabilities to (i) maximise the performance of each design dimension in a cost-efficient way (TCO) and (ii) allow network operators and involved parties to resolve the inherent trade-offs according to their needs and use cases.

In general, the quantification of values will be very challenging, as already discussed in the previous section. However, in some cases interpreting those quantified results in a meaningful way is even more challenging. For example, what does a higher value in trustworthiness mean? The system is more trustworthy, the vendor is more trustworthy or the service is trustworthy? One-dimensional KVI measures might, thus, not be suitable to address the problem; instead, multi-dimensional criteria most likely need to be established to provide meaningful and comparable data regarding a specific value that is to be quantified.

In addition, the scope of a KVI needs to be carefully specified, as it is important contextual information required to interpret and compare solutions. For example, KVIs require a precise definition of E2E. Looking at 5G, E2E is about from one end of network to the other end depending on use cases, which is totally reasonable for KPI definitions. For KVIs, such as sustainability and trustworthiness, we need to carefully define the criteria of what is to be included, as sketched above: do we want to also include the value chain and the use of material and energy resources in the production? There needs to be a balance between the complexity of measuring and quantifying a KVI and its ability to quantify the underlying societal value to provide a real benefit for enabling technologies and the 6G system. Consequently, we need to distinguish between quantitative and qualitative KVIs.

5.3.6 Methodology and way forward

This deliverable contains the mission and rationale behind KVIs and KPIs in Hexa-X and an initial set of research challenges and planned contributions derived from the overall project mission and the core enabling technologies. It serves as a blueprint for the technical work packages with the bottom-up refinement of KPIs and KVIs. This includes, for example, the refinement of “integrated sensing” as a new capability and “location accuracy” as an associated KPI driven by WP3.

Work on KVIs and KPIs will further benefit from technical work packages refining and augmenting the use cases and scenarios during their initial gap analysis phase. The respective work in WP1 (Task 1.1 “Common Vision” and Task 1.2 “Services, use cases”) contributes to the top-down view on KVIs and KPIs.

6 Next Steps

As a next step the content of this report will be updated and extended in the following way:

The 6G Hexa-X vision will be updated and refined based on an additional analysis and in an iterative fashion across all work packages and tasks. Outside-in perspective will be continuously taken into account, including the feedback from the international Hexa-X Advisory Group. A service and use case questionnaire will be developed to collect additional input from project external stakeholders. It will enable Hexa-X to expand and analyze the outside view on services and use cases and refine or extend the current set of use case families and services. KVIs and KPIs will be updated with a mapping to the identified and refined use cases, including quantification of KPIs in the respective use cases wherever feasible. Research challenges in terms of novel KPIs and KVIs will be extended and aligned with the gap analysis activities of technical work packages WP2-WP7.

Additionally, Task 1.5 “Spectrum”, Task 1.6 “Sustainability” and Task 1.7 “Security” will continue to work on an initial set of sustainability targets, initial spectrum requirements and a first draft of security guidelines.

The results of the described work will be reported in Deliverable D1.2.

References

[23.748] 3GPP TR 23.748, "Study on enhancement of support for Edge Computing in 5G Core network (5GC) (Release 17)", v17.0.0, Dec. 2020.

[26.928] 3GPP TR 26.928, “Extended Reality (XR) in 5G”, Release 16, v16.1.1, Dec. 2020.

[29.520] 3GPP TS 29.520, 5G System; Network Data Analytics Services; Stage 3 (Release 17), v17.1.0, Dec. 2020.

[38.174] 3GPP TS 38.174 “NR; Integrated Access and Backhaul (IAB) radio transmission and reception”, Release 16, v16.1.0, Jan. 2021.

[38.821] 3GPP TR 38.821, “Solutions for NR to support non-terrestrial networks”, Release 16, v16.0.0, Jan. 2020.

[38.838] 3GPP TR 38.838, “Study on XR (Extended Reality) evaluations for NR”, Release 17, draft, 0.0.1, Nov. 2019.

[5GA] https://www.whitehouse.gov/briefings-statements/statement-by-the-president-36/#:~:text=The%20Act%20requires%20the%20President,telecommunications%20networks%20and%205G%20technology

[5GP] 5GPPP, https://5g-ppp.eu/

[5GP20] 5GPPP, “Empowering vertical industries through 5G networks – Current status and future trends”, 5GPPP and 5GIA, 2020.

[6GC20] 6G Channel, 2020, https://www.6gchannel.com/

[6GF] https://www.oulu.fi/6gflagship/

[6GF19] 6G Flagship project, “Key drivers and research challenges for 6G ubiquitous wireless intelligence”, Sept. 2019, http://jultika.oulu.fi/files/isbn9789526223544.pdf

[ACI20] 5G ACIA, “Key 5G Use Cases and Requirements”, 2020, https://www.5g-acia.org/publications/key-5g-use-cases-and-requirements/

[AKN20] I.F. Akyildiz, A. Kak, and S. Nie, “6G and Beyond: The Future of Wireless Communications Systems”, IEEE Access, July, 2020.

[ARC20a] https://en.arcep.fr/news/press-releases/view/n/networks-and-the-environment.html

[ARC20b] https://www.archyde.com/paris-gives-itself-four-months-to-decide/

[AYM+20] P. Ahokangas, S. Yrjölä, M. Matinmikko-Blue, V. Seppänen and T. Koivumäki, ”Antecedents of Future 6G Mobile Ecosystems”, 2nd 6G Wireless Summit (6G SUMMIT), Levi, Finland, 2020.

[Bar19] B. Barani, “From 5G PPP to Smart Networks and Services Partnership”, Dresden, Germany, October, 2019, https://www.networld2020.eu/wp-content/uploads/2019/10/barani-dresden-vpub.pdf

[CB20] V. Coroamă and P. Bergmark et al.,” A Methodology for Assessing the Environmental Effects Induced by ICT Services: Part I: Single Services” in proceeding of 7th International Conference on ICT for Sustainability, ICT4S, 2020.

[CB20a] V. Coroamă and P. Bergmark et al.," A Methodology for Assessing the Environmental Effects Induced by ICT Services: Part II: Multiple services and companies" in proceeding of 7th International Conference on ICT for Sustainability, ICT4S, 2020.

[CBR] CBRS, https://www.cbrsalliance.org/

[CHI20] https://internationalfinance.com/china-is-aiming-at-6g-what-next/

[CON20] https://www.connexionfrance.com/French-news/Lille-issues-moratorium-on-controversial-5G-technology-pending-2021-Anses-report

[COR] https://www.corenect.eu

[Dem20] N. Demassieux, "6G. Why?", EUCNC 2020, Dubrovnik, Croatia, June, 2020, https://www.eucnc.eu/wp-content/uploads/2020/07/2020-05-29-6G.-Why-Nicolas-Demassieux-EUCNC-VDEF.pdf

[ECE19] European Commission, "Ethics guigelines for trustworthy AI", report, 2019, https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai

[ECM] European Parliament, "AI rules: what the European Parliament wants", https://www.europarl.europa.eu/news/en/headlines/society/20201015STO89417/ai-rules-what-the-european-parliament-wants

[EC19] European Commission, "The European Green Deal", https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[EC20] "A New Industrial Strategy for Europe", COM(2020) 102 final - Brussels, March, 2020, https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf[EPAI] European Parliament, "EU guidelines on ethics in artificial intelligence: Context and implementation", 2019, https://eumass.eu/wp-content/uploads/2020/03/EU-guidelines-on-ethics-in-AI-Briefing-2019.pdf

[ECA18] https://ec.europa.eu/futurium/en/ai-alliance-consultation

[ECC15] https://ec.europa.eu/environment/circular-economy/

[ECE17] https://ec.europa.eu/jrc/en/publication/eu-code-conduct-energy-consumption-broadband-equipment-version-6

[ECS12] https://ec.europa.eu/environment/eussd/smgp/policy_footprint.htm

[Eri20a] Ericsson, "Ever-present intelligent communication", Whitepaper, 2020, https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g

[Eri20b] Ericsson, "The Internet of Senses" report, 2020, https://www.ericsson.com/en/reports-and-papers/consumerlab/reports/10-hot-consumer-trends-2030-connected-intelligent-machines

[Eri20c] Ericsson, https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf

[EXP20] Exponential roadmap, 2020, https://exponentialroadmap.org/wp-content/uploads/2020/03/ExponentialRoadmap_1.5.1_216x279_08_AW_Download_Singles_Small.pdf

[FAI] https://www.fairphone.com/en/

[Fet20] G. Fettweis, "6G - Just a better 5G?", 2020 5G World Forum keynote series, November, 2020, https://ieeetv.ieee.org/2020-5g-world-forum-keynote-gerhard-fettweis

[GSM19] GSMA, "The Enablement Effect, The impact of mobile communicatons technologies on carbon emission reductions", 2019, https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf.

[GSM14] GSMA, "Arbitrary Radio Frequency exposure limits: Impact on 4G network deployment", 2014, https://www.gsma.com/publicpolicy/wp-content/uploads/2014/03/Arbitrary-Radio-Frequencyexposure-limits_Impact-on-4G-networks-deployment_WEB.pdf

[GSM20] GSMA, "2020 Mobile Industry Impact Report: Sustainable Development Goals", September, 2020. https://www.gsma.com/betterfuture/2020sdgimpactreport/wp-content/uploads/2020/09/2020-Mobile-Industry-Impact-Report-SDGs.pdf?utm_source=better_future_site&utm_medium=search_engine&utm_campaign=2020_SDG_impact_report

[HYJ+20] B. Han, S. Yuan, Z. Jiang, Y. Zhu, and H. D. Schotten, "Robustness Analysis of Networked Control Systems with Aging Status," in the 2020 IEEE International Conference on Computer Communications (INFOCOM) Poster Session, Toronto, Canada, July, 2020, https://ieeexplore.ieee.org/document/9162929

[ICT52] 5G-PPP, https://5g-ppp.eu/5g-ppp-phase-3-6-projects/

[TSD20] TSDSI, 2020, https://tsdsi.in/tech-deep-dive-2020/

[LUM12] LUMA institute, "Innovating for people: Handbook of human-centered design methods", Pittsburgh, US, 2012.

[ITU18] https://www.itu.int/en/ITU-T/focusgroups/net2030/Pages/default.aspx

[ITU20] ITU-T, Methodology for environmental life cycle assessments of information and communication technology goods, networks and services, https://www.itu.int/rec/T-REC-L.1410/en

[ITU20a] ITU-T, "Additional Representative Use Cases and Key Network Requirements for Network 2030", June, 2020.

[ITU20b] ITU-T, "Representative use cases and key network requirements for Network 2030", January, 2020.

[JM18] J. Malmodin and D. Lundén, "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015", Sustainability, 10(9):3027, August, 2018. https://doi.org/10.3390/su10093027

[Jap20] Ministry of Internal Affairs and Communications, https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/pressrelease/2020/6/30_7.html

[Kor20] 6G World, "Korea lays out plan to become the first country to launch 6G", November, 2020, https://www.6gworld.com/exclusives/korea-lays-out-plan-to-become-the-first-country-to-launch-6g/

[LL19] M. Latva-aho and K. Leppänen, “Key drivers and research challenges for 6G ubiquitous wireless intelligence”, 6G Research Visions 1, September, 2019, http://jultika.oulu.fi/files/isbn9789526223544.pdf

[MAA+20] M. Matinmikko-Blue, S. Aalto, M. Asghar, et al., "White Paper on 6G Drivers and the UN SDGs” White paper, 6G Research Visions 2, University of Oulu, Finnland, 2020, http://urn.fi/urn:isbn:9789526226699

[MLC17] J. Manyika, S. Lund, M. Chui et al, “Jobs lost, jobs gained: what the future of work will mean for jobs, skills, and wages”, 2017.

[EGM20] ETSI GS MEC 002, "Multi-access Edge Computing (MEC), Phase 2: Use Cases and Requirements", v2.1.1, October, 2018.

[MIT10] Mitcheson PD. Energy harvesting for human wearable and implantable bio-sensors. Annu Int Conf IEEE Eng Med Biol Soc. 2010;2010:3432-6. doi: 10.1109/IEMBS.2010.5627952. PMID: 21097254

[MLC20] R. Minerva, G. M. Lee, and N. Crespi, “Digital twin in the oT context: A survey on technical features, scenarios, and architectural models,” Proceedings of the IEEE, vol. 108, no. 10, pp. 1785–1824, 2020. https://ieeexplore.ieee.org/document/9120192

[MLA+17] M. Matinmikko, M., Latva-aho, P. Ahokangas, et al. ”Micro operators to boost local service delivery in 5G”, Wireless Personal Communications, vol. 95, no. 1, pp. 69–82, May, 2017.

[MLA+18] M. Matinmikko, M. Latva-aho, P. Ahokangas, and V. Seppänen, ”On regulations for 5G: Micro licensing for locally operated networks”, Telecommunications Policy, vol. 42, no. 8, pp. 622-635, September, 2018.

[MSM+20] C. Maringe, J. Spicer, M. Morris, et al., “The impact of the COVID-19 pandemic on cancer deaths due to delays in diagnosis in England, UK: a national, population-based, modelling study”, July, 2020, https://www.thelancet.com/journals/lanonc/article/PIIS1470-2045(20)30388-0/fulltext

[MYP20] M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, ”Moving from 5G in Verticals to Sustainable 6G: Business, Regulatory and Technical Research Prospects”, CrownCom, 2020.

[NGA] NEXT G ALLIANCE, https://nextgalliance.org/

[NGM21] https://www.ngmn.org/ngmn-news/press-release/ngmn-board-has-launched-a-project-focussing-on-the-vision-and-drivers-for-6g.html

[Nok20a] Nokia Bell Labs, “Communications in the Era of 6G”, White Paper, 2020, https://onestore.nokia.com/asset/207766

[Nok20b] Nokia, “Enterprise Digital Transformation Through Industry 4.0”, 2020, https://pages.nokia.com/T00507-ABI-Report.html?_ga=2.199450926.1649835083.1604997903-298906622.1592235641

[Nok20c] Nokia, “The AI Opportunity for telecoms”, 2020, https://www.nokia.com/networks/research/the-ai-opportunity-for-telecoms/

[NTT20] NTT DOCOMO_White paper, "5G Evolution and 6G" January, 2020, https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_20200124.pdf

[OMH+20] T. Ojala, M. Mettälä, M. Heinonen, P. Oksanen, "Ecologically sustainable digitalisation contributes to climate targets Final report of the working group preparing an ICT climate and environment strategy". Ministry of Transport and Communications Finland, 2020.

[Phi17] I. Philbeck, "CONNECTING THE UNCONNECTED, Working together to achieve", Connect 2020 Agenda Targets, ITU White Paper, 2017.

[Pou20] A. Pouttu, "6G White Paper on Validation and Trials for Verticals towards 2030's", 6G Research Visions 4, University of Oulu, 2020. http://urn.fi/urn:isbn:9789526226811

[RSP] https://rspg-spectrum.eu/2020/12/questionnaire-of-the-sub-group-on-role-of-rsp-to-help-combat-climate-change/

[Sam20] Samsung, "6G – The next hyper-connected experience for all", 2020, https://cdn.codeground.org/nsr/downloads/researchareas/20201201_6G_Vision_web.pdf

[Shi19] The Shift Project, "LEAN ICT: TOWARDS DIGITAL SOBRIETY": OUR NEW REPORT ON THE ENVIRONMENTAL IMPACT OF ICT", 2019, https://theshiftproject.org/en/article/lean-ict-our-new-report/

[Sen19] Information report from the French Commission on environmental impact of digital (in French), http://www.senat.fr/rap/r19-555/r19-555-syn.pdf

[SNS] 5G IA, SNS Horizon Europe, https://5g-ia.eu/sns-horizon-europe/

[Rac20] Racontour, "The economic impact of 5G", https://www.raconteur.net/infographics/the-economic-impact-of-5g/

[RRS+19] J. Randers, J. Rockström, P. Stoknes, U. Goluke, D. Collste, S. Cornell, and J. Donges, "Achieving the 17 Sustainable Development Goals within 9 planetary boundaries", Global Sustainability, 2, E24. doi:10.1017/sus.2019.22

[Rus15] S. Russel, "Value alignment", World Economy Forum, 2015, https://www.youtube.com/watch?v=WvmeTaFc_Qw.

[UN15] United Nations, "Transforming our world: the 2030 Agenda for Sustainable Development", Resolution adopted by the General Assembly, September, 2015, https://upload.wikimedia.org/wikipedia/commons/d/d5/N1529189.pdf

[UN19] United Nations, "The Sustainable Development Goals Report 2019", 2019, https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

[VM20] H. Viswanathan and P. Mogensen, "Communications in the 6G Era", IEEE Access, March, 2020.

[WEF20] World Economic Forum, "The Global Risks Report 2020", January, 2020, https://www.weforum.org/reports/the-global-risks-report-2020

[YMA20] S. Yrjölä, M. Matinmikko-Blue, and P. Ahokangas, "How could 6G Transform Engineering Platforms Towards Ecosystemic Business Models?", 2020 2nd 6G Wireless Summit (6G SUMMIT), Levi, Finland, 2020.

[YAM20a] S. Yrjölä, P. Ahokangas and M. Matinmikko-Blue, "White Paper on Business of 6G", University of Oulu.

[YAM20b] S. Yrjölä, P. Ahokangas and M. Matinmikko-Blue, "Sustainability as a Challenge and Driver for Novel Ecosystemic 6G Business Scenarios", Sustainability, Vol. 12, No. 21.

[ZY20] V. Ziegler and S. Yrjola, "6G Indicators of Value and Performance," 2020 2nd 6G Wireless Summit (6G SUMMIT), pp. 1-5, doi: 10.1109/6GSUMMIT49458.2020.9083885, Levi, Finland, 2020.

[ZVF+20] V. Ziegler, H. Viswanathan, H. Flinck, M. Hoffmann, V. Räisänen and K. Hätönen, "6G Architecture to Connect the Worlds," in IEEE Access, vol. 8, pp. 173508-173520, 2020, doi: 10.1109/ACCESS.2020.3025032., 2020.