HEXA-X-II

6G use cases, requirements, drivers and vertical needs

6G series workshop by Hexa-X-II

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hexa-x-ii.eu

Introduction

Sustainable and value driven approach for 6G

WP1 - Value, requirements and ecosystem

Overall Objective	**WP1 will set the prerequisites to define a 6G system**
Objective 1	Ensure foundation of 6G design will integrate environmental, social and economic sustainability
Objective 2	Define use cases and determine requirements to drive 6G design
Objective 3	Connect HEXA-X-II with the business ecosystem & anchoring 6G in society

Design 6G to deliver value and to be sustainable

Sustainability is the key value and driver in Hexa-X-II, encompassing the three pillars…

- Environmental sustainability
- Social sustainability (incl. Trustworthiness and inclusion)
- Economic sustainability

… the duality

- **Sustainable 6G**: 6G should be inherently designed to meet sustainability commitments (NetZero,…)
- **6G for sustainability**: 6G-based services enabling other sectors/verticals to minimize their impact

… and involve society

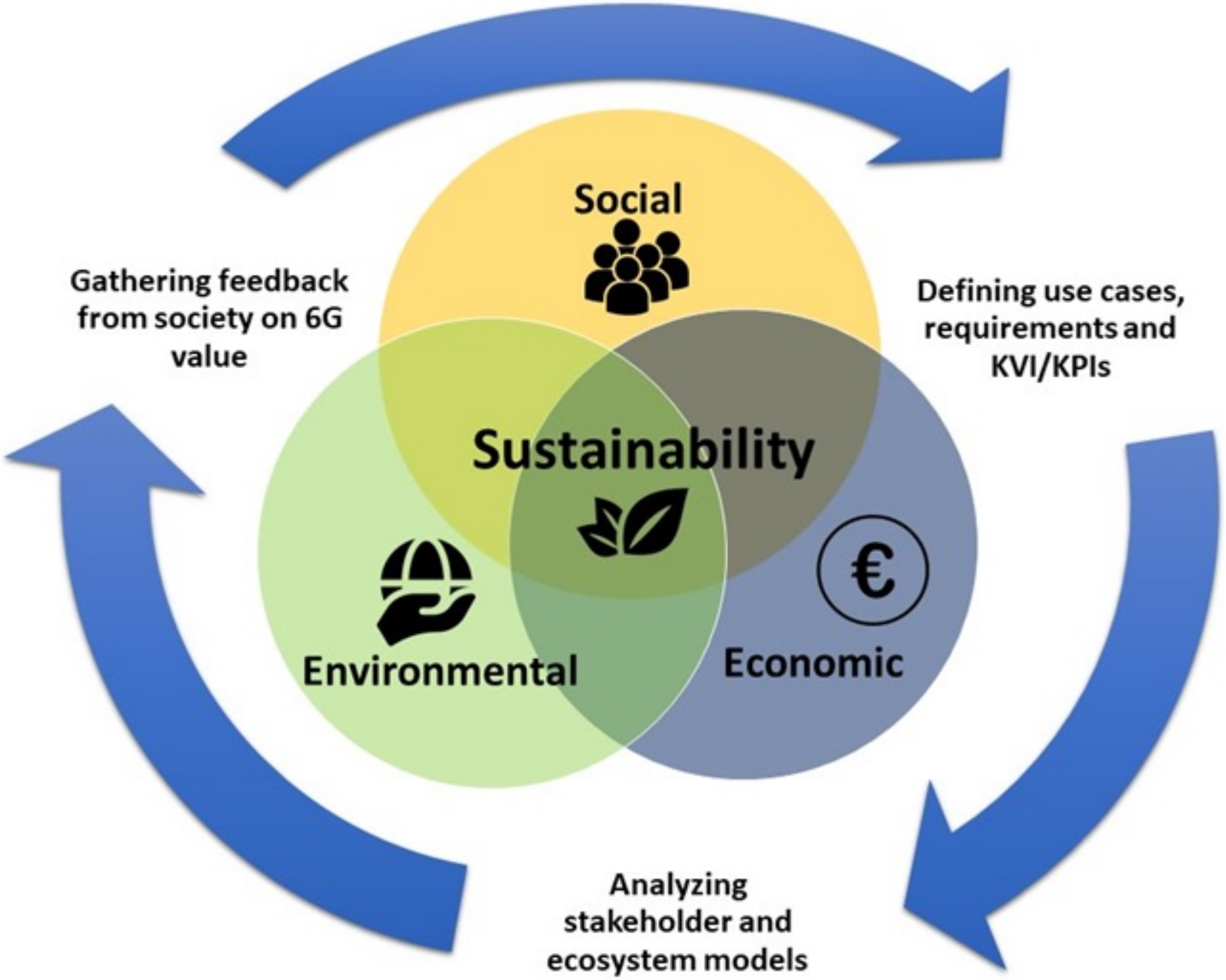
- Obtain **feedback on 6G value** addressing their needs and concerns

to define use cases and requirements

- Extract **requirements**, **Key Performance Indicators** and **Key Values and Indicators**

and analyse stakeholders & ecosystem models

- Identify key **stakeholders** and define **business and revenue models** and establish the **6G ecosystem**



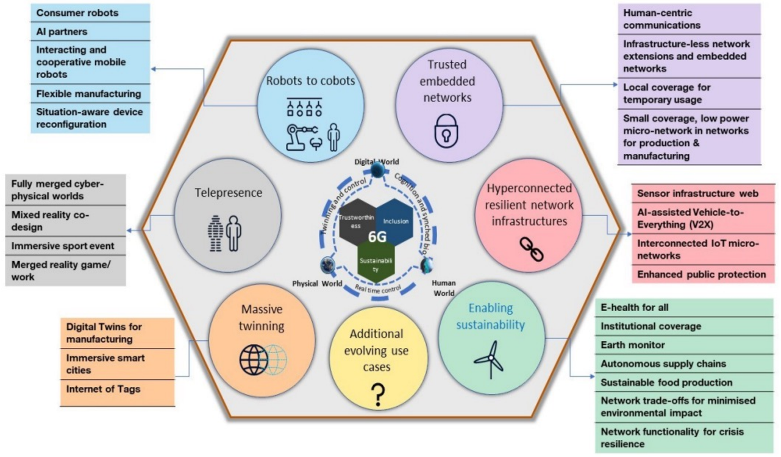
WP1 - Work at a glance

D1.1 - Environmental, social and economic drivers and goals for 6G (June 2023)		
Provide Drivers & Goals for 6G Design	**Provide Initial Set of Use Cases**	Sustainability Guidelines for 6G Design
D1.2 - 6G use cases and requirements (December 2023)		
Provide a consolidated view on use cases and requirements for 6G	Present a scenario for channel model	Give first insights on the business and revenue model for 6G ecosystem
D1.3 – Environmental and societal impacts of 6G (March 2024)		
Provide a comprehensive view of the business ecosystem	Provide an analysis of the challenges and risks to meet all sustainability domains	Give first view on feedback from society
D1.4 – 6G Value, requirements and ecosystem (April 2025)		
Provide the final analysis on the value to be created by 6G for society & people	Provide the final set of use cases and requirements	Present the outcome of various exchanges with the ecosystem

Hexa-X-II Use cases

Hexa-X-II Use Case Families

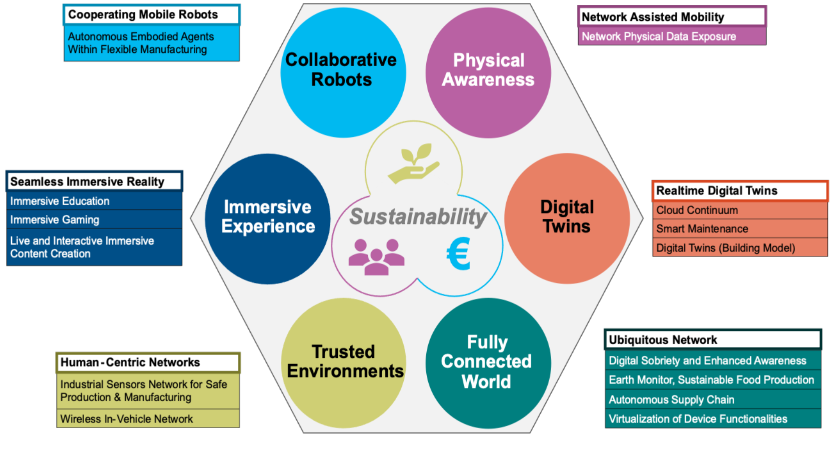
Go beyond Hexa-X by **considering environmental, social, and economic sustainability aspects** as the three pillars for these 6G use cases



Creation of 6 new Use Case Families

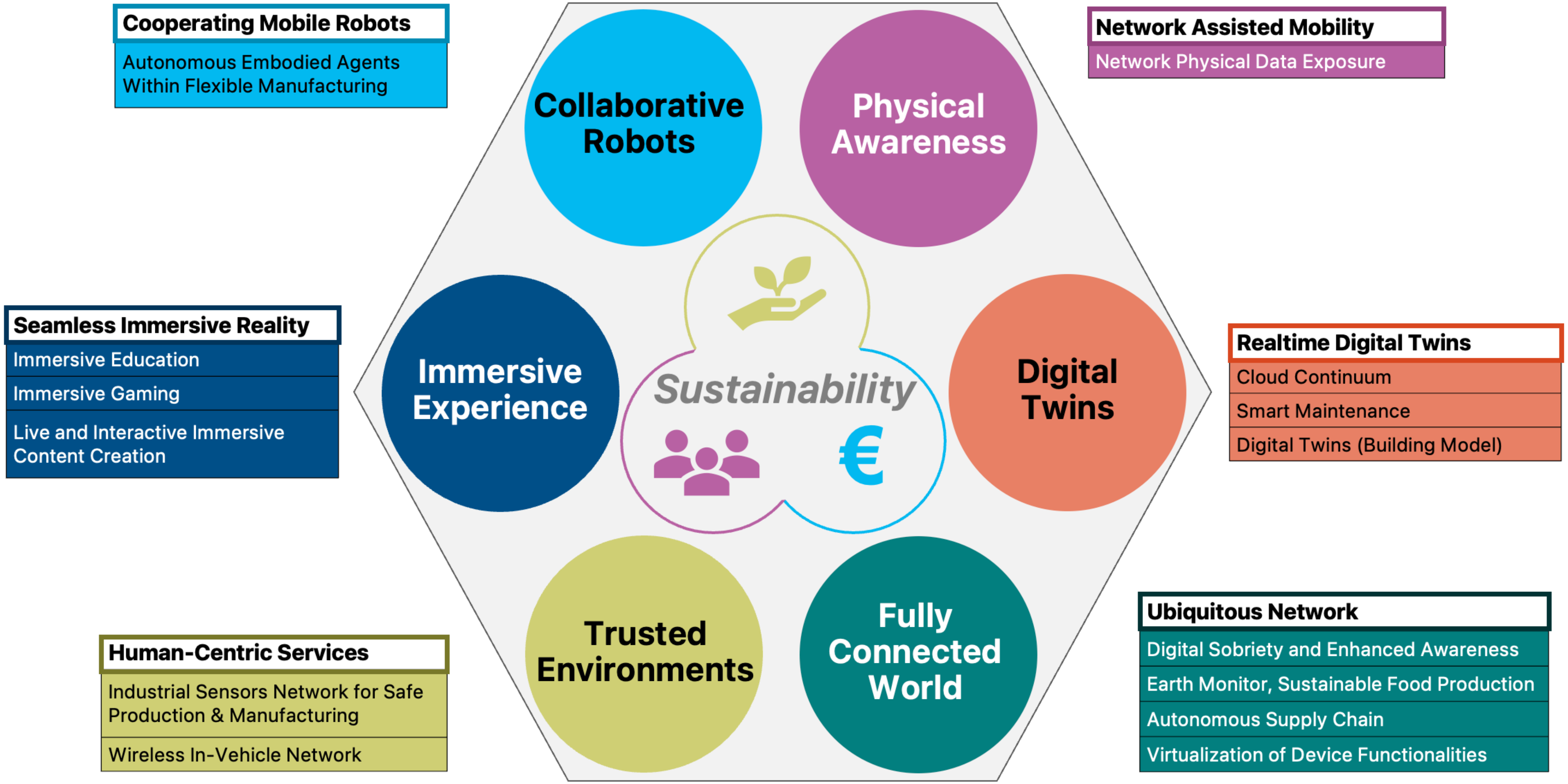
6 "Representative Use cases" for deeper analysis

- ➢ One per family representing the key aspects of the family
- ➢ Analysis provides a sustainability analysis, requirements, and KPIs, among other aspects



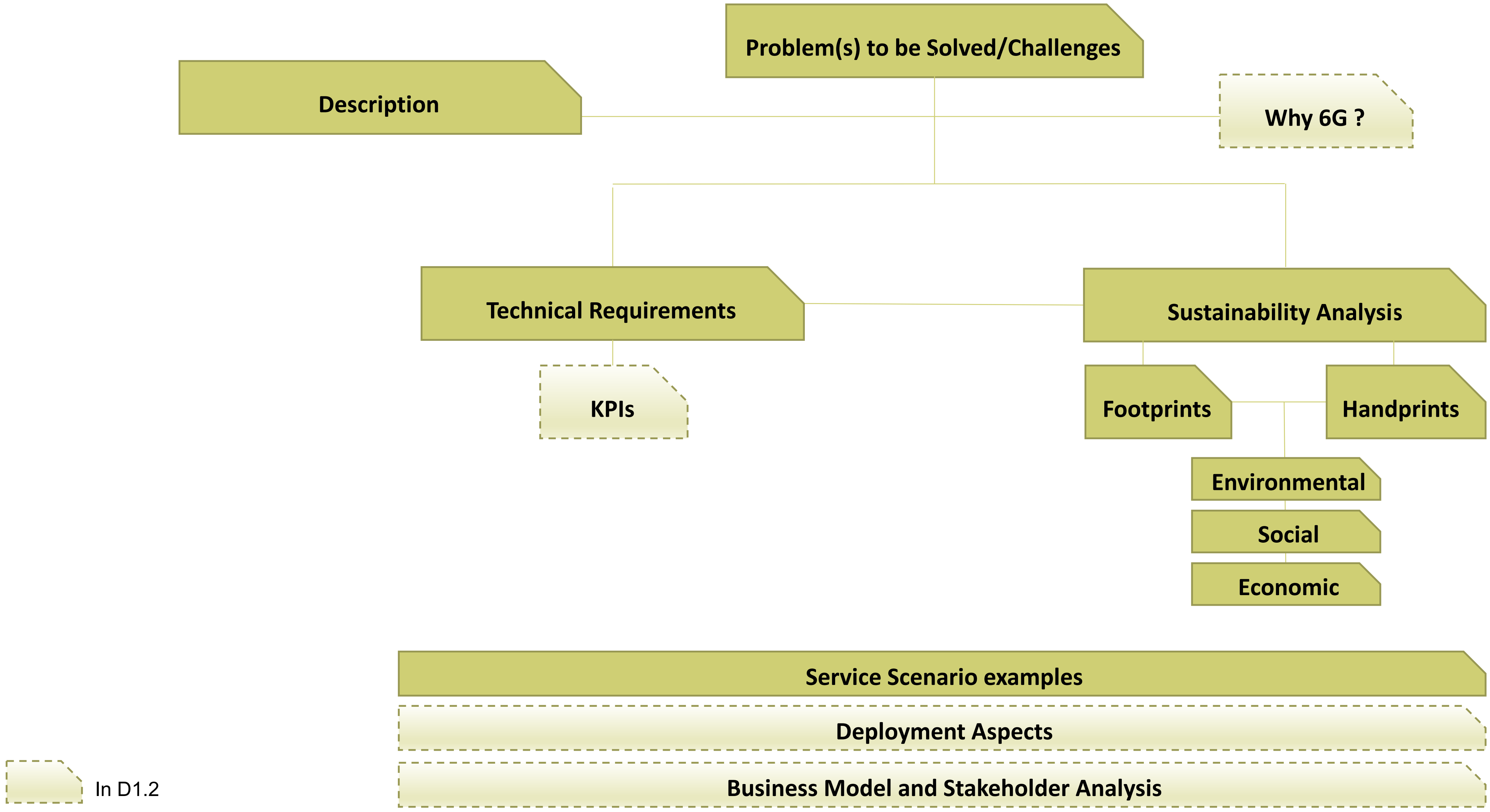
Hexa-X-II Use Cases with Highlighted Representative Use Cases

Hexa-X-II Use Case Families



Hexa-X-II Use Cases with Highlighted Representative Use Cases

Use Case Analysis Methodology (more details in Deliverable D1.2)



Seamless Immersive Reality

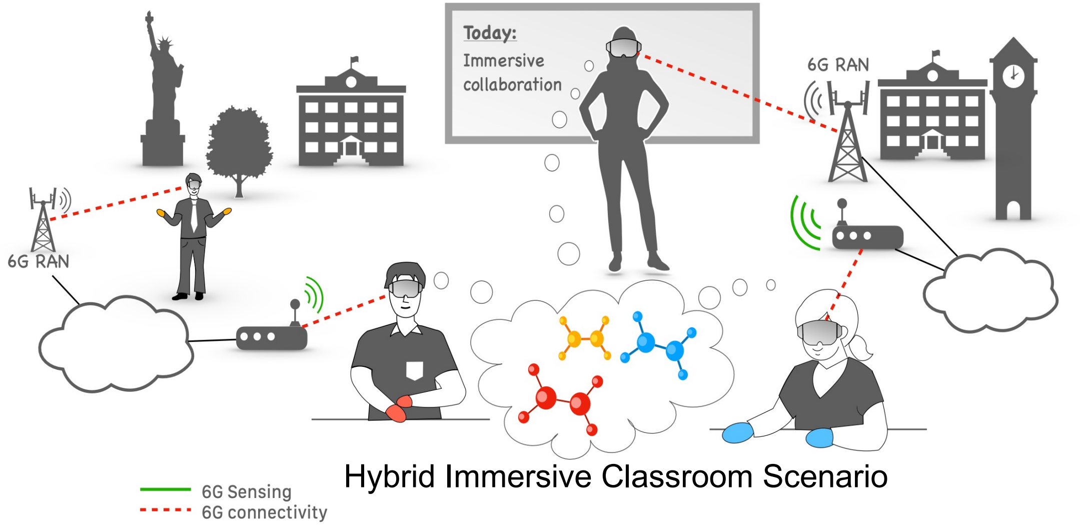
Immersive Experience

Description

- Based on XR technology for fulfilling the human need for immersive digital environments
- Combines mixed reality collaboration and immersive telepresence.
- Offers a quality of interaction with remote participants almost as realistic as if physically present

Applications

- Work: Office, construction site
- Education: Immersive learning experiences
- Healthcare: Applications for medical training or remote consultations
- Cultural and Social: Museums, immersive games



Hybrid Immersive Classroom Scenario

Sustainability Analysis

	Handprints	Footprints
Env.	• Increased resource efficiency • Reduced need for extensive venue infrastructure	• Increased electronic waste • Increased material and energy consumption
Social	• Enhanced opportunities • Enhanced and interactive cultural, and social experiences	• Potential digital divide and inequalities depending on access • Privacy and trustworthiness concerns • Loss of human physical contact
Eco.	• Improved efficiency, productivity, and profitability • Efficient virtual training environments	• Massive initial investment • Service and maintenance costs

Problem(s) to be Solved/Challenges

- Enabling significantly improved quality of experience (QoE)
- Living and working from anywhere
- Achieve seamless service continuity
- Ensure privacy protection

Technical Requirements

- **AI/ML and Compute Capabilities** – Device embedded or provided by the network
- **Sensing** – Joint Communication and Sensing (JCAS)
- **Positioning accuracy** – Network-based positioning
- **Privacy protection**
- **Service continuity** – minimum level across diverse locations
- **Synchronization between participants and data streams** – Low E2E latency

Cooperating Mobile Robots

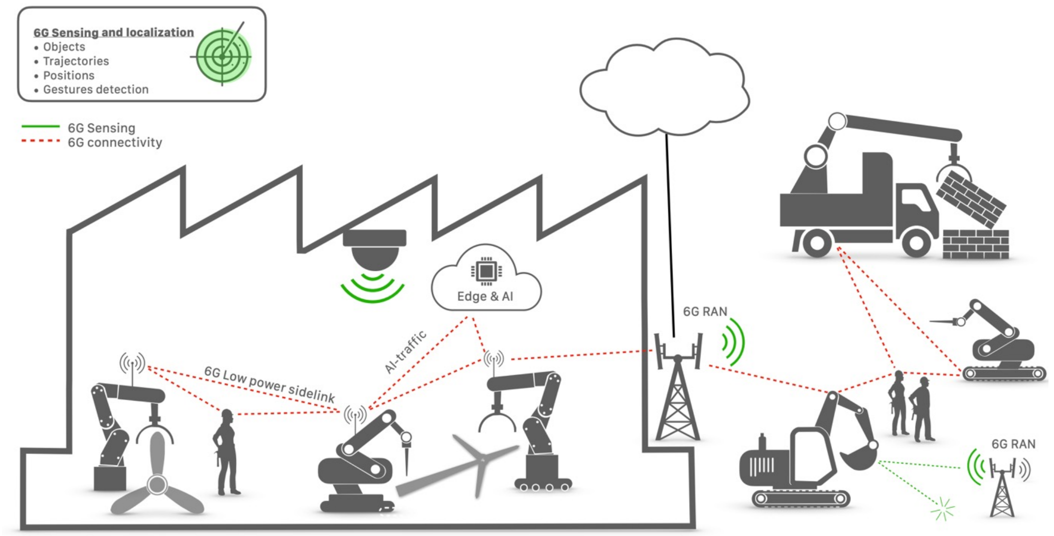
Collaborative Robots

Description

- Autonomous robots, possessing mobility, environmental sensing, and task-execution capabilities
- Robots engage in communication with each other, other machines, and nearby humans, collaborating to achieve common objectives

Applications

- Autonomous, collaborative, interactive, cooperative mobile robots
- Industrial manufacturing
- Smart living
- Construction sites



Sustainability Analysis

	Handprints	Footprints
Env.	• Increased efficiency in production processes • Reduced need for multiple machines due to function integration	• Increased material and energy consumption throughout full life cycle of the robots and associated services • Increased electronic waste
Social	• Improved accessibility from tasks beyond human capabilities • Safer working environments • M2H support	• Elimination of jobs • Uneven distribution of benefits from robots and cobots • Unauthorized use of sensors and associated privacy concerns
Eco.	• Enhanced productivity and competitiveness • New business and job opportunities	• Barriers for small businesses • Monopolization risks • Financial loss in case of service failure or cyber-attacks

Problem(s) to be Solved/Challenges

- Understanding communication requirements of machines in the future
- Using limited resources efficiently
- Adapting to dynamic requirements of the market
- End-user access to custom manufacturing
- Safe and trustworthy interactions with tools that can make decisions

Technical Requirements

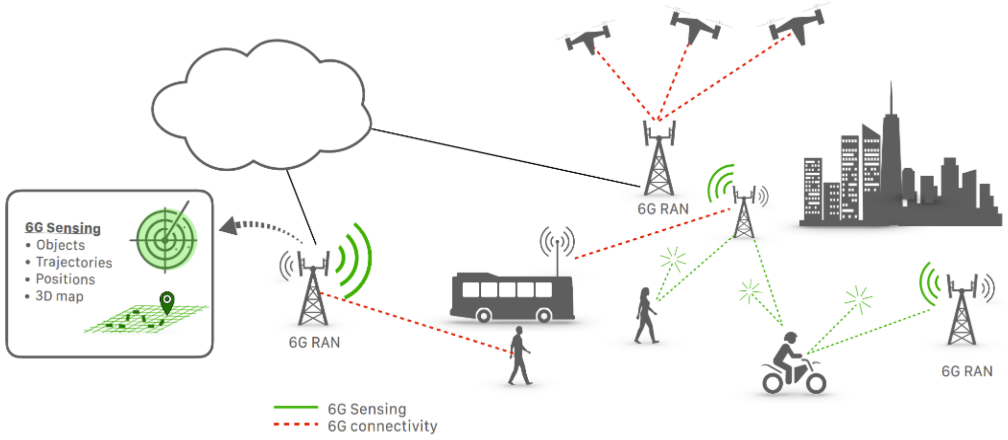
- **Local ad hoc connectivity** – formation of task specific, localized, temporary subnetworks embedded in campus network
- **Reliable and low latency communications** – Service-level reliability and E2E latency
- **Mobility** – Frequent handovers as machines join and leave. Subnetworks nomandic behavior and roaming may occur
- **Sensing, positioning, and AI/ML** – within networks and devices (JCAS) introduction of AI/ML traffic types and AI/ML execution in edge nodes for enhanced coordination and accuracy

Network-Assisted Mobility

Physical Awareness

Description

- Vehicles (cars, AGVs, drones, etc.) depend on network nodes and devices for localization, determining object properties, and accessing contextual information, with reliable network connections and services within a defined area



Problem(s) to be Solved/Challenges

- Risk of accidents with intense and automated transport scenarios
- GHG emissions from transport
- Cost of transportation of goods
- Access to reliable transport
- Privacy in public spaces

Applications

- Network assistance (warnings, trajectories, etc.)
- Network assistance map (3D map)
- Full operation (remote control of vehicles)
- Context-aware communication (beam forming, path selection, etc.)

Sustainability Analysis

	Handprints	Footprints
Env.	• Reduced GHG emissions from improved traffic flow, supported driving, and electric vehicules • Reduced accidents and automotive waste	• Increased energy consumption to support compute needs, sensing, and real-time requirements • Usage of material for additional infrastructure
Social	• Enhanced road safety and well-being • Enhanced availability of transportation, continuity of service	• Privacy concerns associated to localization data • Wrong decisions made by AI
Eco.	• Improved profitability from using the network for the monitoring tasks instead of additional sensors	• Expenses of network infrastructure to meet reliability requirements

Technical Requirements

- **Privacy** – Handling personal identities in public spaces
- **Localization** – High wide-area coverage for positioning and sensing services, also in 3D, and high detection probability of unconnected objects
- **Connectivity** – High resilience, availability, and reliability for connectivity in 3D
- **Compute** – Availability of reliable compute capabilities offered by the network

Realtime Digital Twins

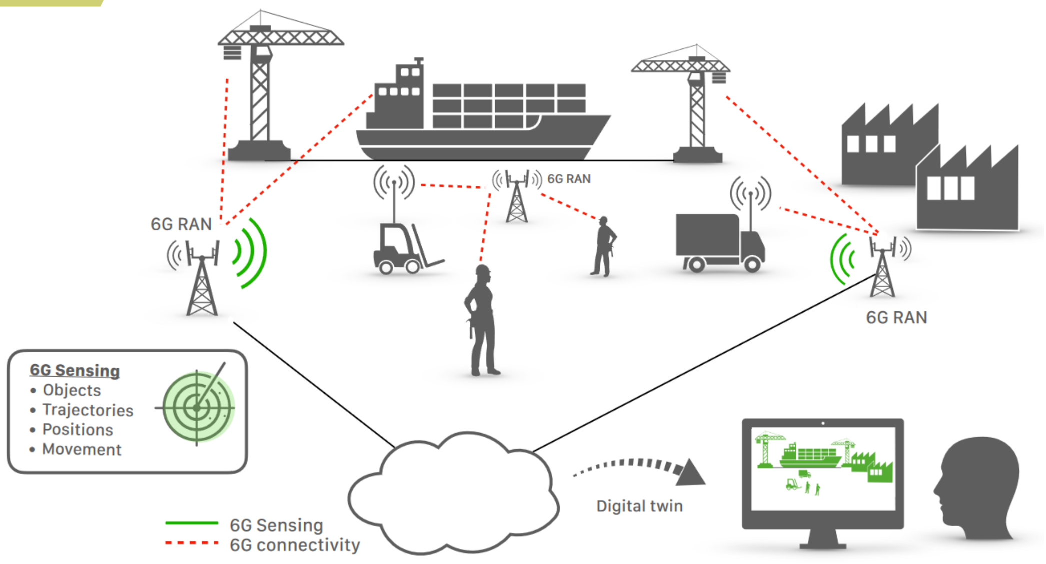
Digital Twins

Description

- Digital representation of real-world entities, encompassing processes, products, individuals, and functionalities, applicable to industries, smart cities, or construction.
- This contextual digital equivalent of the real world offers a unified access to users/agents and is used for interaction, control, prediction, test, maintenance, and management of processes and components.

Applications

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



Sustainability Analysis

	Handprints	Footprints
Env.	• Improved monitoring and usage of natural resources • Sustainable urban development • Avoided visits to monitored areas	• Resource intensive IoT (sensors, devices) and electronic waste • Increased energy consumption for data processing, data centers, computing resources
Social	• Reduced human work load • Enhanced accessibility to drinking water and food supply • Trustworthiness on data due to real-time monitoring	• Privacy risks in events of cyber-attacks • Potential impact on labor market and employability
Eco.	• Improved efficiency from optimized operations • Profitability gains	• Increased costs in multi-stakeholder ecosystems • Increased business risks from reliance on technology

Problem(s) to be Solved/Challenges

- Increase production quality and efficiency
- Prevent situations where humans are put at risk
- Guaranty the privacy & trustworthiness
- Accessibility of DT models

Technical Requirements

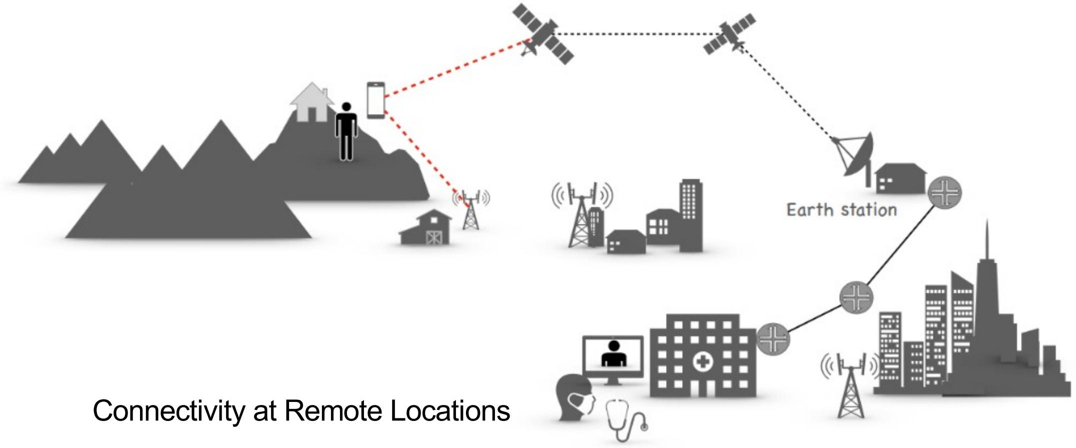
- **Realtime aspect** – Low E2E latency
- **Full coverage** – Indoor and outdoor areas with the appropriate QoS levels
- **Network Sensing** – Reduces the need for external sensors
- **Sensors** – Required for all extra data
- **Compute resources** – Integrated AI
- **Privacy/trustworthiness –** Supported by a secured network
- **Hierarchy of Digital Twins –** Overarching DT's interoperability, "massive twinning"
- **M&O capabilities –** For flexible resource allocation, and orchestration of sensing/sensor data
- **Interoperability –** Using Open interfaces for more flexible and manageable network
- **Strong system integrators –** Due to low compatibility and multiple technologies (networks, sensors, domain specific software)

Ubiquitous Network

Fully Connected World

Description

- Aims to provide mobile broadband connectivity to every human globally, eliminating connectivity gaps in remote, challenging, and diverse geographical areas
- Uses both Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN), including satellites, HAPS, air-to-ground networks, and drones.



Connectivity at Remote Locations

Problem(s) to be Solved/Challenges

- Digital inclusion
- Reduce educational and health-services gaps
- Enabler for earth monitoring
- Delivers increased network resilience, crucial in the event of disasters

Applications

- Most users will be able to benefit from a wide set of services with reliable connectivity, including high-quality voice or video streaming services
- Crisis Management
- Digital health services
- Autonomous supply chains

Sustainability Analysis

	Handprints	Footprints
Env.	• Preventing travel-related emissions due to remote service access • Env. data collection from earth monitoring	• Increased material, energy, and land use to build the ecosystem • Increase of e-waste if not handled properly
Social	• Accessibility to digital services • Enhanced trustworthiness (availability and accountability) • Network resilience and better response to crisis	• Digital divide related to IT literacy, aging population, etc. • Privacy risks for digital services
Eco.	• Economic resilience from wider availability • Economic benefits from new opportunities and enabled applications	• Profitability challenge from network investment and maintenance costs

Technical Requirements

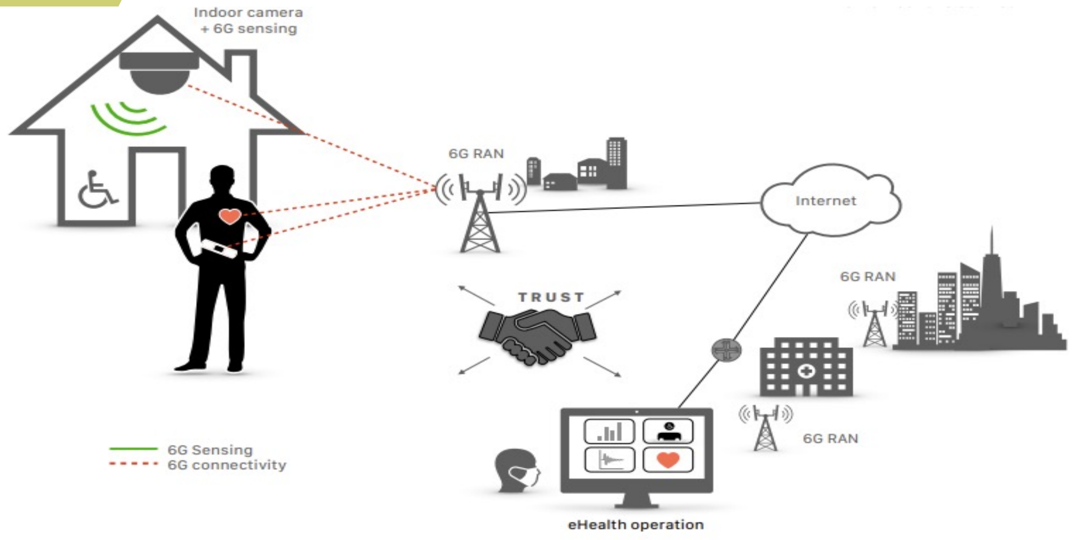
- **Connectivity –** Cover any “white zones” (outdoor and indoor)
- **Resilience –** Basic services must be guaranteed
- **Flexibility** – Flexible network topologies providing different possibilities to connect
- **Service Continuity –** Integration between terrestrial and non-terrestrial networks
- **Privacy and Security –** Regardless of the access network and during handovers between each
- **Affordability:** cost-efficient E2E ecosystem for widespread adoption

Human-Centric Services

Trusted Environments

Description

- Focuses on placing the human at the center of a diverse range of services.
- Prioritizes trusted environments with key characteristics of privacy and reliability for public trust



Problem(s) to be Solved/Challenges

- Extended access to high-end health monitoring and diagnosis
- Deliver safe environments for increased well-being, mental health, safety, inclusion, and autonomy
- Safety, health, and peace of mind for hard-hat workers, as well as visitors of big public events

Applications

- Precision Healthcare: Personalized diagnosis, treatment, and health monitoring
- Safe Environments: Well-being, safety, and autonomy in places like kindergartens, schools, homes, and workplaces.
- Public Safety during Big Events: Using human-centric information such as location and personalized data for public safety services.

Sustainability Analysis

	Handprints	Footprints
Env.	• Reduced GHG emissions from less commuting and optimized use of travel infrastructure • If used for healthcare, potential reduced in medical waste	• Increased material and energy use for new devices, network deployment, AI/ML, e-health • Increase of e-waste from body sensing and computing devices
Social	• Improved quality of life for people needing continuous health monitoring • Enhanced trustworthiness and human safety	• Emerging risks from monitoring humans • Potential risks for trustworthiness/safety in case of hacking
Eco.	• Efficiency improvements and reduced costs • Economic predictability from creating trust with human-centric services	• Pressure on demand side can impact efficiency • Safety degradations from new risks related to new services

Technical Requirements

- **High privacy protection –** Enabled by new techniques such as local anonymization, pseudonymization, advanced information coding and additive homomorphic technology. In addition, physical privacy solutions are required for a body-subnetwork of sensors, actors, and evaluation devices.
- **High service reliability –** When talking human-centric services, the reliability of the services is key for the user trust. Besides, in scenarios such as safe environments or public safety, a high service availability is crucial to avoid catastrophic situations.

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6GSNS

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Seamless Immersive Reality

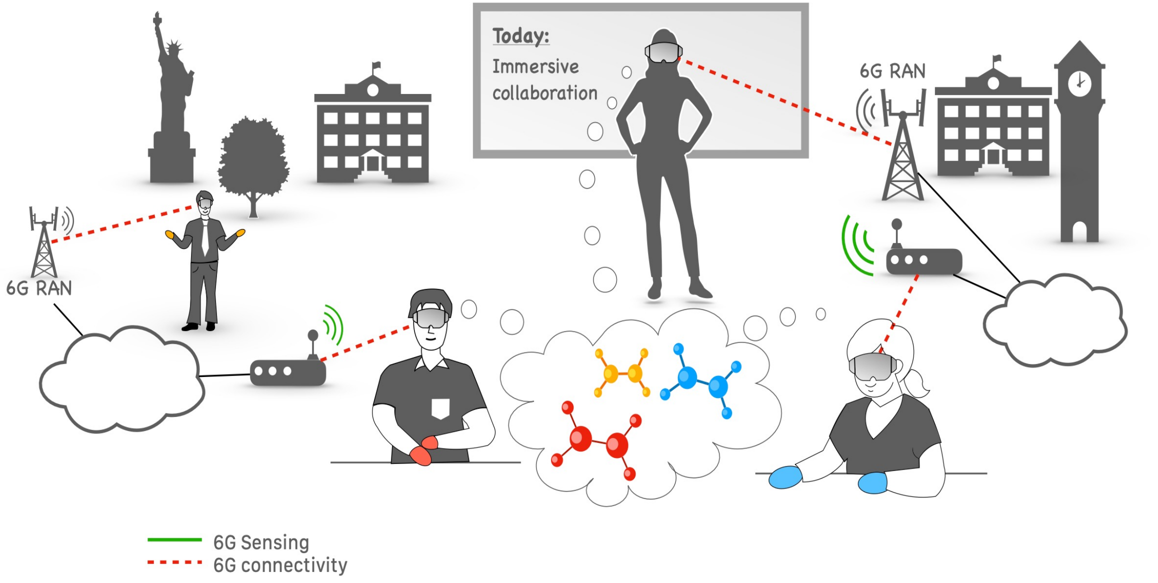
Immersive Experience

Combines mixed reality collaboration and immersive telepresence use cases, referring to seamless real-time interaction with collocated and remote participants and (digital representations of) physical or virtual objects blended into a physical or virtual environment. Seamless Immersive Reality offers a quality of interaction with remote participants (or objects) almost as realistic as if the remote persons (or objects) were present in the same room or physical environment.

This improved quality of experience facilitates interaction, collaboration, co-presence, and co-experience in many if not all aspects of life including aspects of work, be it in the office or on a construction site, education, or healthcare, as well as aspects of our cultural, social, and personal life like enjoying augmented objects in a museum or an immersive game with friends.

Problem(s) to be Solved/Challenges

- Enabling significantly improved quality of experience
- Living and working from anywhere
- Achieve seamless service continuity
- Ensure privacy protection



** digital representation of real object*

Seamless Immersive Reality: Sustainability Analysis

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

Seamless Immersive Reality: Requirements and KPIs

Requirements

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

KPIs

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

Cooperating Mobile Robots

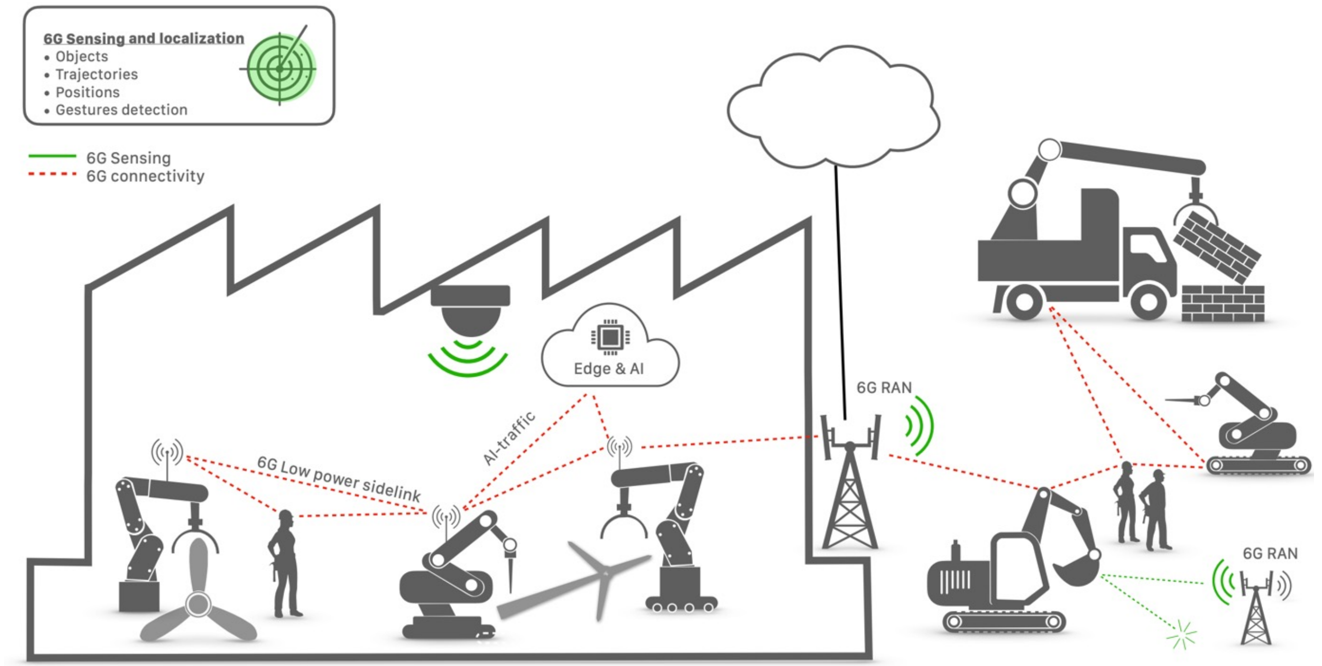
At the centre of this use case are autonomous robots with the ability to move, sense their environment, and perform a productive task. These robots can communicate with one another, with other machines, and with nearby humans to perform individual tasks that contribute to a common cooperative objective.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

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

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

Problem(s) to be Solved/Challenges

- Understanding and addressing the communication requirements of machines in the future
- Using limited resources efficiently
- Adapting to dynamic requirements of the market
- End-user access to custom manufacturing
- Safe and trustworthy interactions with tools that can make decisions



Cooperating Mobile Robots: Sustainability Analysis

Collaborative Robots

	Sustainability Handprints (benefits)	Sustainability Footprints (cost)
Environmental	• Resource efficiency: Functionalities may be provided by machines with less materials, energy, and waste generated • Function integration eliminates the need for multiple dedicated machines with individual functions	• Energy is consumed and materials are used to manufacture, deploy, and operate robots and associated services • The manufacturing, including material extraction and industrial processes, and transportation of robots generate GHG emissions • The disposal of machines and devices results in increased electronic waste
Social	• Accessibility: help people perform tasks beyond human capabilities • Safer work environment. • Increased trustworthiness of on-time delivery of the expected outcomes • M2H support: Robots could fulfil assistance roles, such as supporting the elderly at home	• Rendering roles obsolete: may eliminate job roles involving manual, linear, and repetitive tasks • Robots and cobots may require human operators to obtain new skills w.r.t. their method of use and maintenance (IT/robots literacy) • Benefits of robots and cobots might not be distributed evenly among society • People's privacy may be breached by unauthorized use of robots' and cobots' sensors
Economic	• Increased productivity and enhanced competitiveness • New business opportunities may emerge from technology leadership in autonomous robotics • New business opportunities for individuals: Cf. "Accessibility" in "Social benefits" • New job opportunities	• Extra R&D investments. • Initial investments to purchase, install, and set up autonomous machines may be a barrier for smaller businesses or those in developing countries. • Increased reliance on robots/cobots can pose a risk in case of failures or cyber-attacks • Monopolization risks • The use of autonomous machines can raise new regulatory and legal issues

Cooperating Mobile Robots: Requirements and KPIs

Collaborative Robots

Requirements

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

KPIs

	KPI	Target Range	Justification
Communication	User-experience data rate [Mb/s]	< 10	Data rate between robot and campus network. Can be significantly higher locally in a subnetwork where raw sensor data and/or AI/ML traffic is exchanged.
	Connection density [devices/m^2]	< 0.1	Mobile robots occupy an area of 1 m2, and it is assumed that they occupy at most 10% of the overall area to ensure fluent mobility. The world's largest industrial manufacturing campuses accommodate thousands of robots.
	Mobility [km/h]	< 20	Slow vehicular
	End-to-end latency [ms]	< 0.8	Industrial machines may exchange coordination messages up to 200 times per second and can be triplicated for redundancy. This results in a transfer interval of ca. 1.66 ms. E2E latency limit is set to at most half that interval to ensure enough margin for ARQ. [22.104]
	Service-level reliability [%]	99.999 – 99.99999	Application-side safety net mechanism like "survival time" and "grace period" are employed to compensate occasional packet losses and delays at link level. Selected applications may have an even more strict reliability requirement up to 99.999999% [22.104].
	Coverage [%]	—	Localized nature of a joint task makes local ad hoc connectivity favourable.
Positioning & New Capabilities	Positioning accuracy [m]	< 0.1 (fine) < 1 (coarse)	Tasks such as environment mapping, robot navigation, and inventory management require fine positioning. Tasks like robot localization need coarse positioning.
	Sensing-related capabilities [Y/N]	Y	Robots and cobots depend on capturing the environmental context. Network-integrated sensing may complement or replace dedicated on-board sensors. Efficient transport of data/information from connected external sensors likely needed.
	AI/ML-related capabilities [Y/N]	Y	Robots and cobots depend on advanced machine learning. Execution may be embedded in the device and/or offloaded at a local edge and/or provided by the network as an over-the-top service.

Network-Assisted Mobility

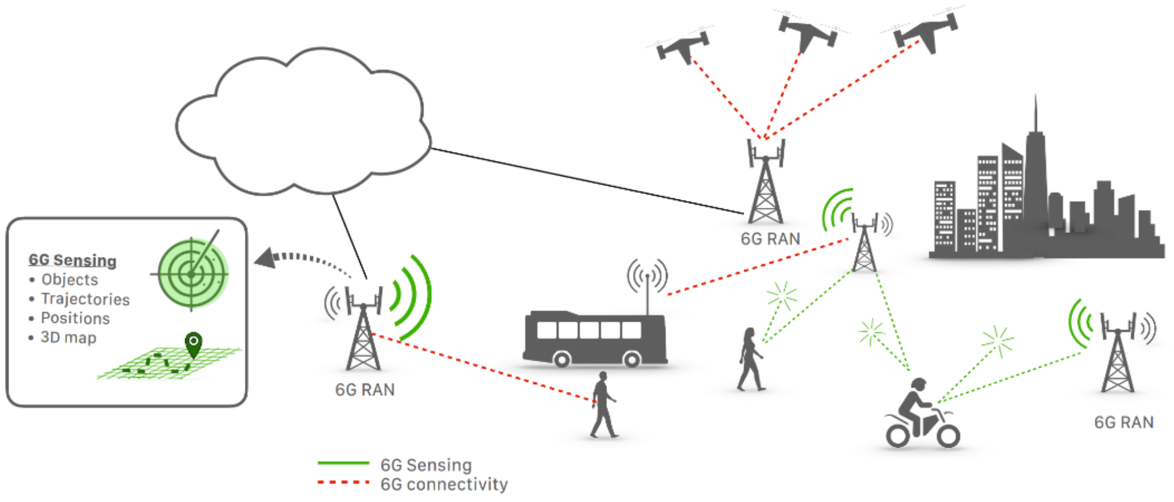
In this use case, vehicles (cars, AGVs, drones, etc.) are relying on the network nodes and devices for localization of connected and unconnected objects and for determination of their properties such as size and velocity, contextual info, trajectories etc. Vehicles have a reliable connection to the network,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

This can be done on several levels; networks can provide raw or processed environment and position data, or navigational support ranging from collecting and sharing of data, over navigation assistance, to full operation, leveraging on beyond-communication capabilities. The network can thereby support vehicles with different levels of autonomy and different modes of operation and enable smart transport in urban areas. Furthermore, there is a possibility to use the physical environment understanding around nodes and devices to improve communication to vehicles by tailoring beams, avoid blockers, etc.

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

Problem(s) to be Solved/Challenges

- Risk of accidents with intense and automated transport scenarios
- Energy consumption and generated emissions from transport
- Cost of transportation of goods and people
- Access to reliable transport
- Privacy in public spaces



Network-Assisted Mobility: Sustainability Analysis

Physical Awareness

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

Network-Assisted Mobility: Requirements and KPIs

Requirements

- **Privacy**: personal identities in public spaces must be handled in such a way that privacy is not jeopardized.
- **Localization**: Network nodes need to be able to perform radar-like measurements using the radio interface, to detect unconnected objects, which is delivered by JCAS functionality. In conjunction with this capability, precise device positioning is required. For both these capabilities, it is expected that networks will only be able to deliver part of the required precision and coverage. A sensor fusion functionality would therefore be needed, where networks collect data from multiple sources, e.g. onboard camera and GPS, and fuse it with the network measurements to create an enhanced dataset that is shared with the device and other devices.
  - High wide-area coverage for positioning and sensing services, also in 3D.
  - High detection probability of unconnected objects.
- **Connectivity**: Reliable communication is a critical aspect of this use case. For safety reasons, the link to the network should not be allowed to go down other than during very short periods within the service area. This may be difficult to achieve in practice considering 3D mobility within a city where links may be blocked at times. But the network should have the capability to predict and notify the connected vehicles such that they can take preventive action (e.g. stop or switch to a local operation mode). The network should also be able to timely activate adjacent links to ensure connectivity, e.g. to other devices and networks.
  - High resilience, availability, and reliability for connectivity in 3D; preferably without requiring excessive deployment of network nodes.
- **Compute**: Offload from the vehicles to the network of heavy processing tasks and training of models should be supported, as well as in-network real-time processing of sensor data. This means that the networks should have the capability of reliable compute and AI/ML-related functionality that can be accessed at all times from any point in the network.
  - Availability of reliable compute capabilities offered by the network.

KPIs

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

Realtime Digital Twins

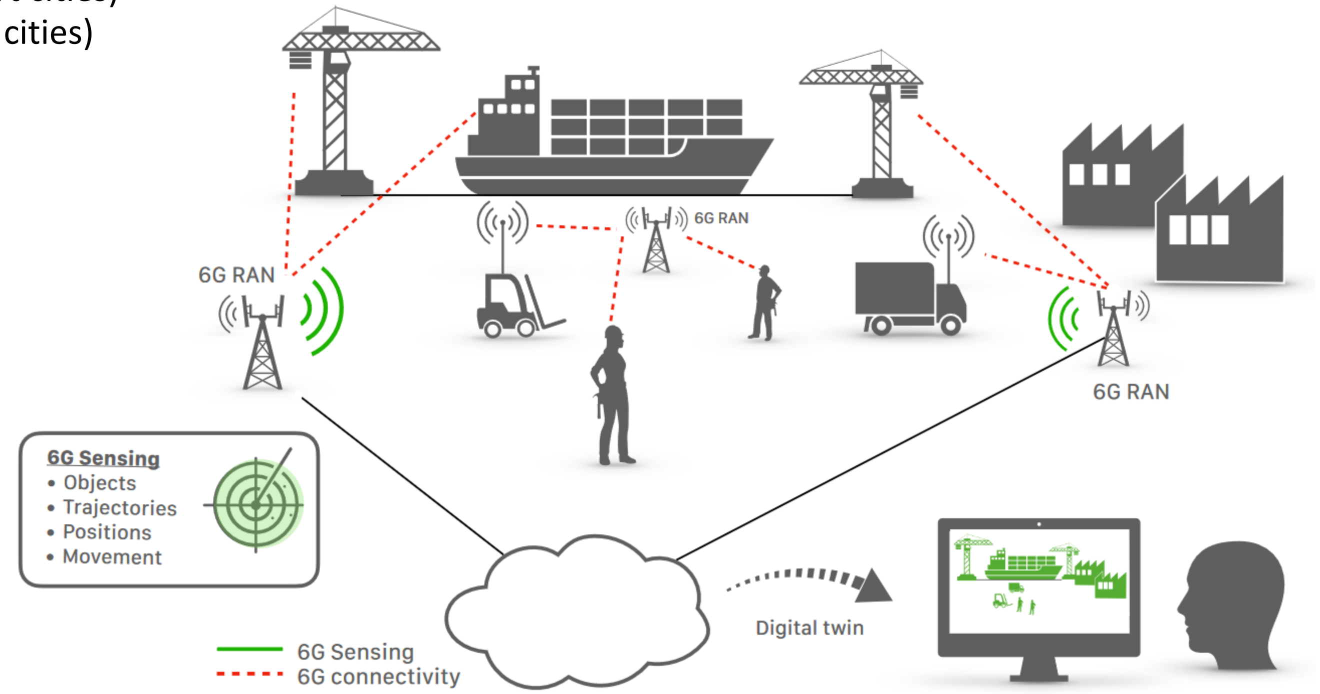
A digital twin is an accurate digital representation of any combination of processes, products, persons, and functionalities of real-world items such as for industry, smart cities, or construction. This contextual digital equivalent of the real world offers a unified access to users and/or agents and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

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

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

Problem(s) to be Solved/Challenges

- Increase production quality and efficiency
- Prevent situations where humans are put at risk
- Guaranty the privacy & trustworthiness
- Accessibility of DT models



Realtime Digital Twins: Sustainability Analysis

Digital Twins

	Sustainability Handprints (benefits)	Sustainability Footprints (cost)
Environmental	• Reduced usage of natural resource (e.g., water management, smart cities) by improved monitoring • Reduced waste from the increase of the production quality and efficiency • Sustainable urban development • Reduced GHG emissions from avoided visits to monitored areas, and avoiding operations visits for network planning and operation	• Resource intensive IoT and material required to produce sensors and IoT devices • Electronic waste resulting from the deployment of sensors and equipment • Energy consumption required for processing real-time data, DT generation, data centres, IoT devices, and computing resources
Social	• Reduced dependency on humans (e.g., 24/7 monitoring), leading to increased well-being for humans • Enhanced inclusion/opportunities for particular roles, irrespective of age, gender, disabilities, etc • Increased trustworthiness on data /information availability due to real time monitoring /control • Enhanced accessibility to drinking water and food and its management from DT related to water/food supply, agriculture, etc	• Potential risks to the privacy in the event of a cyber-attack • Potential impact on employability and labour market. Must be studied further
Economic	• Economic efficiency improvements from optimizing operations via digital twins • Improved resilience and flexibility • Improved safety from using digital twin for virtual safety checks • Improved profitability from avoiding costs from problems by using digital twin for optimizing operations (avoiding delays and saving costs including testing before production with end users/customers)	• Possible increased costs from complexity of multi-stakeholder ecosystem • Increased costs from energy, digital twin model, equipment, training, maintenance • Safety/predictability of operations – increased business risk from using technology instead of human perception

Realtime Digital Twins: Requirements and KPIs

Requirements

- **Realtime aspect:** The very low E2E latency is mandatory to achieve a Realtime DT.
- **Full coverage:** The full physical geography of the DT needs to have complete network coverage with the appropriate QoS levels, including both indoor and outdoor areas and the locations without Line of Sight. Any handover in the network needs to be seamless.
- **Network Sensing:** the DT model is based on real-time data collected from the physical world. All sensing data collected by the network itself, eliminates the need for external sensors and reduces the complexity of the DT ecosystem and logistics.
- **Sensors:** Connected sensors are required for all extra data that cannot be provided by the network sensing, to create an accurate replica of the complex Realtime environmen,. These sensors might also need a technology evolution beyond the current sensor devices for the sensitivity/accuracy.
- **Improved human-machine interaction**: For an effective DT, it is crucial for users to have a seamless immersive interaction with the DT. To achieve this, all the capabilities/features as defined by the “immersive experience” use case family (also including the high-resolution 3D rendering) are required. (These are not duplicated here).
- **Compute** resources to handle the complex DT models and databases with the integrated advanced AI skills to simulate, steer and predict.
- **Privacy/trustworthiness** supported by a secure network. Especially for smart cities, it will be crucial for the end-users to guarantee the privacy of the collected data.
- **Hierarchy** of Digital Twins: DTs will be covering larger, more complex systems as full cities and/or factories. As DT’s will first appear on lower level (machine level, one production line, one specific utility in a city), there will be overarching DT’s popping up to cover the full systems with the requirement to ingest, incorporate a number of underlying DT’s (hierarchy/interop). This is also called “set of twins” or “massive twinning”.
- **M&O capabilities** for the RT DT service to cope with the flexible resource allocation, since compute can be spread over the network core, edge, device. Also, the sensing/sensor data collection needs to be orchestrated: Not all included devices in the DT will have sufficient sensor capabilities and compute resources on board and will need to delegate this to the network (sensing and edge resources) or to other, better equipped devices in the vicinity.
- **Interoperability:** The DT might include deployed proprietary and legacy systems. Using open interfaces can make the network more flexible and more manageable (also from orchestration perspective).
- **Strong system integrators** for the complex implementation of the RT DT, due to low compatibility and multiple technologies (networks, sensors, domain specific software, other digital twin systems)

KPIs

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

Ubiquitous Network

Fully Connected World

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

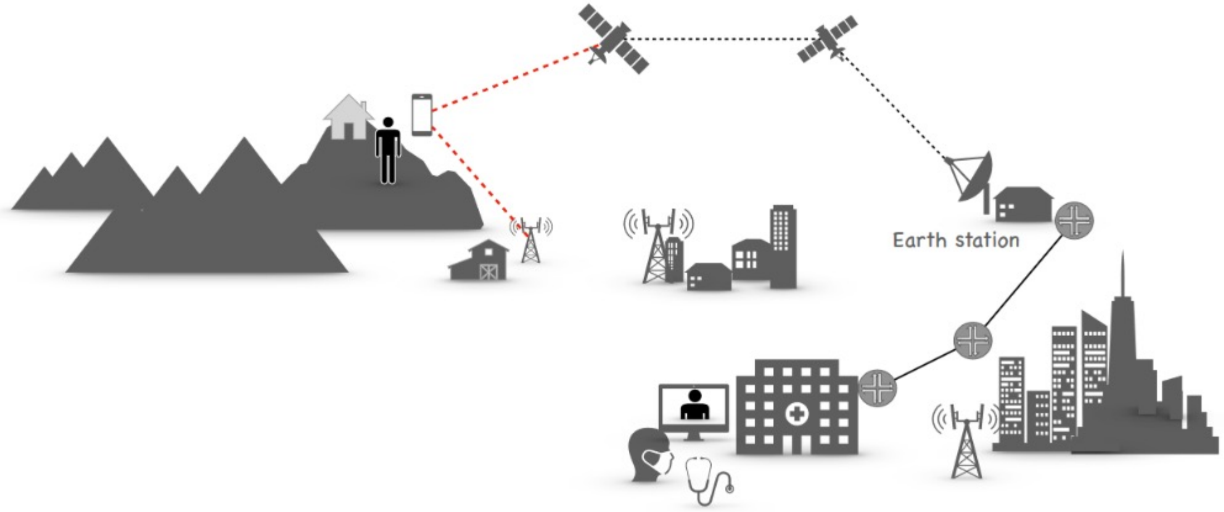
This ubiquitous network will be enabled through seamless access to both TN and NTN – including satellites, High Altitude Platform Stations (HAPS), air-to-ground networks, and unmanned aerial vehicles/drones – in a transparent way for the end user, meeting the requirements (e.g., bit rates, latency) to ensure that every-day needs are covered, with the desired quality of service (QoS). Although most users in these areas will not be able to enjoy the services with the utmost performance (e.g., no URLLC, or the most immersive experiences), they will be able to benefit from a wide set of services with reliable connectivity, including high-quality voice or video streaming services. Moreover, the configuration could also enable other 6G-related use cases, such as compute offloading if the technical/physical limitations allow it (e.g., no URLLC due to the use of satellites).

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

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

Problem(s) to be Solved/Challenges

- Digital inclusion
- Reduce educational and health-services gaps
- Enabler for earth monitoring
- Delivers increased network resilience, crucial in the event of disasters



Ubiquitous Network: Sustainability Analysis

	Sustainability Handprints (benefits)	Sustainability Footprints (cost)
Environmental	• Preventing travel-related emissions as a result of remote access to services • Enabling collection of environmental data for Earth monitoring • Access to precise status information can enable precision farming practices (agriculture, aquaculture) to reduce the use of fertilizers, pesticides, and fresh water	• Increased material and energy use to build this ecosystem (e.g., devices, base stations, satellites) • Increased land use (e.g., networks, data centres) could potentially impact existing habitat, and thus, biodiversity • Potential increase of e-waste on land, oceans and space if not handled properly (e.g., collection, 100% biodegradable)
Social	• Providing everyone access to the digital ecosystem • Providing access to digital services to all (e.g., entertainment, education, transactions, voting, etc.) à Bridging the digital divide • Contribute to making networks reliable (perception), everywhere • Enhanced trustworthiness of digital services (availability and accountability) • Delivering increased resilience in networks, crucial in unexpected events (e.g., natural disasters) • Enhanced healthcare and education to reach new areas • Increases food yield from enhanced agricultural management • New job opportunities	• Potential digital divide for people with functional variation / ageing population / IT literacy if all services are meant to be handled digitally • Potential risk to privacy if all services are meant to be handled digitally • Potential mental health problem due to possibility of always being connected and being traceable
Economic	• Improved economic resilience from wider availability of connectivity for different services • Efficiency improvements from the reuse of resources • Economic benefits (profitability) to society/country from combining ubiquitous network with other use cases (e.g. in public services)	• Profitability challenge from the network investment • Resilience challenges from the maintenance of network

Ubiquitous Network: Requirements and KPIs

Requirements

- **Connectivity**: The 6G system will need to provide ubiquitous access even in the most remote or hard-to-reach areas with extreme coverage needs. The range of the network will need to be extended to cover any "white zones" (outdoor and indoor) even in areas where it is not possible to deploy dedicated network infrastructure. Finally, it is not only required to provide connectivity in the surface, but also allow for 3D coverage targeted at commercial drone operations or deep underground areas where signal conditions are very poor.
- **Resilience**: The 6G system should be able to ensure resilient, seamless operation even in environments with intermittent or limited network connectivity. Services characteristics might vary through the coverage area, but basic services must be guaranteed.
- **Flexibility**: The 6G system must be able to deploy flexible network topologies (based on different accesses) to overcome obstacles such as limited infrastructure or signal attenuation/interference. End-user devices must be able to connect with different possibilities, e.g., allowing connection or offloading to a better proximity or more resource-efficient/capable device, or via multi-hop scenarios.
- **Service Continuity:** Tight integration between different topologies and network elements is needed, including the integration between terrestrial and non-terrestrial networks so service continuity can be assured for devices moving between different network topologies or deployments.
- **Privacy and Security:** Privacy and security requirements must be consistent and guaranteed, regardless of the access network (TN or NTN), and during handovers between each.
- **Affordability:** It is crucial to provide a cost-efficient E2E ecosystem (end-user devices, network infrastructure/operation) to ensure widespread adoption.
- **6G-NTN convergence**: In the vast part of the world, where fixed networks are not much deployed due to topography or high costs of deployment or low investment capability, mobile and NTN should push convergence where terrestrial-based and NTN-based solutions can complement each other, however having different service and cost characteristics. All necessary services should work properly, irrespective of the network in which the service is running on. Additionally, the convergence of these two networks requires that parameters, or other information, currently being used for a particular action will be provided by both TN and NTN. An example of such is the information related to "to which base station a handset is connected", which enables emergency alerts to be sent (e.g., sending tsunami threat alarms to all devices connected to base stations near the coastline in a given region).

KPIs

	KPI	Target Range	Justification
Communication	End-to-end latency [ms]	10-100	Depending on the service. It is targeting video calls/streaming. 'Real-time' interactions are not considered as part of this requirement (e.g., no remote surgeries).
Communication	Reliability [%]	99.9 –99.999	The reliability KPI could be associated with the expected service (e.g., given NTN coverage, what is the probability of successfully fallback from TN to NTN and achieving a data rate of at least 100 kb/s). Success rate for this should be high.
Communication	Availability [%]	98.5	Tightly connected to reliability (qualifying the success of transmission) is the availability of connectivity (qualifying the percentage of time the service can be delivered). Appropriate combination of full coverage and capacity to deliver video streaming-like services is required. Reaching new areas can promote new use cases/businesses/ services. As there is no viable alternative, those services will fully rely on this connectivity (e.g., Health services require high reliability and availability of the connectivity). Also, Maintainability requirements need to be high for them not being a cause for downtime. Moreover, the ecosystem needs to be designed in a fully reliable and resilient way in case of emergencies. As deployment cannot be defined through design, KPIs such as 'seconds of system downtime upon handover' could be implemented.
Communication	User experienced data rate [Mb/s]	0.1 –25 Downlink/ 2 Uplink	Good quality video streaming should be delivered (not extreme experience). The data rate refers to a single UE, measured on the device. Based on current standards, from 0.1 (sensor data) to 25 Mb/s (4K video, based on current video requirements) are the expected bit rates, at least for Downlink. It may be revisited based on the evolution of video standards by 2030.
Communication	Connection density [devices/m^2]	0.1	Connection density is not a stringent requirement, as it does not target massively connected deployments. Also, connection densisty for rural areas are low. However, urban settings could require 0.1 devices/m², in case of crisis scenario.
Communication	Coverage [%]	- Up to 10-15 km range (cell radius) for TN - 99.9% earth human environment on earth area coverage with TN/NTN	Coverage means both extending the range of terrestrial networks, reaching larger cell size, but also the percentage of coverage of a given area, combining the different types of access, TN and NTN.
Communication	Mobility [km/h]	up to 120	Mobility related to seamless handover between TN and NTN. It should support terrestrial vehicle speed's
Positioning & New Capab.	Location accuracy [m]	Low (≈ 10)	Global coverage option is not prone to high accuracy requirements.
Positioning & New Capab.	Sensing [Y/N]	N	Sensing usually not needed, except for some specific cases (during a crisis to obtain information)
Positioning & New Capab.	AI/ML-related capabilities [Y/N]	N	AI services can be provided offline, utilizing big data analytics. It might require AI capabilities to tweak routes, or other outcomes to minimize disruption time.

Human-Centric Networks

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

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

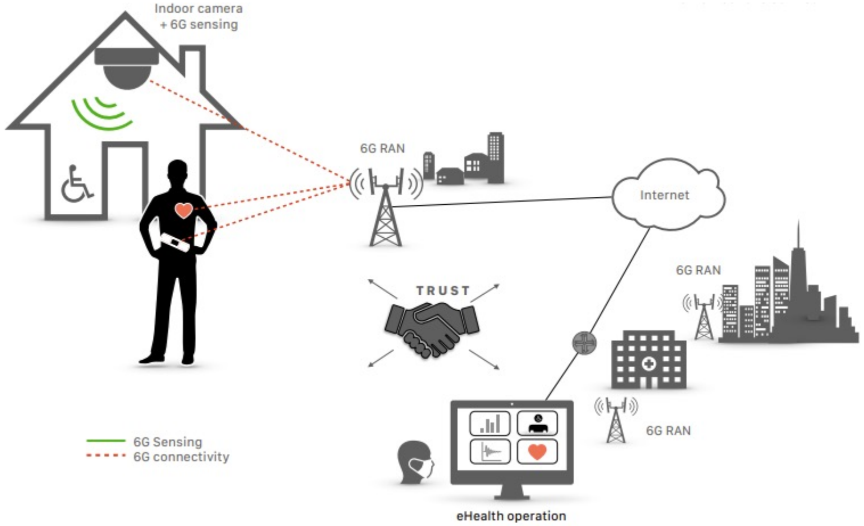
Safe environments such as kinder gardens, schools, homes, day-care, workplaces, or hospitals will be of help to establish well-being, safety, inclusion, autonomy for children, elderly, and people with disabilities. Sensing and AI/ML compute for accurate localization, spatial- and situation-awareness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

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

Human-centric services impose very high privacy requirements not only comprising consent management but even more so technical solutions such as anonymization, pseudonymization, advanced information coding, or additive homomorphic technologies. Moreover, solutions to privacy protection cannot exclusively reside in the application domain and must be built into the 6G system. To guarantee the safety of thousands of people at a big event or of hundreds of workers on a construction or a chemical manufacturing site, the 6G network deployment needs to achieve very high service availability or service reliability.

Problem(s) to be Solved/Challenges

- Extended access to high-end health monitoring and diagnosis
- Deliver safe environments for increased well-being, mental health, safety, inclusion, and autonomy
- Safety, health, and peace of mind for hard-hat workers, as well as visitors of big public events



Human-Centric Networks: Sustainability Analysis

Trusted Environments

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

Human-Centric Networks: Requirements and KPIs

Trusted Environments

Requirements

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

- **High service reliability:** when talking human-centric services, the reliability of the services is key for the user trust. Besides, in scenarios such as safe environments or public safety, a high service availability is crucial to avoid catastrophic situations.

KPIs

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