›DESIRE6G‹

D2.1: Definition of Use Cases, Service Requirements and KPIs/KVIs

HEU 6G SNS JU Project

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Abstract

This deliverable documents the selection of use cases to be used for the definition of the DESIRE6G system architecture and also for showcasing and validating the project achievements. The use cases are defined by means of KPIs and functional requirements, that are used to derive the requirements of the DESIRE6G system. A set of KVIs are also identified for the use cases selected.

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Keywords

6G, use cases, KPIs, KVIs, requirements, AR/VR, Digital Twin, robot control

Disclaimer

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List of Acronyms

3GPP	3rd Generation Partnership Project
AI/ML	Artificial Intelligence / Machine Learning
AIaaS	Artificial Intelligence as a Service
AR	Augmented Reality
CPU	Central Processing Unit
DPU	Data Processing Unit
DT	Digital Twin
E2E	End-to-End
FPGA	Field Programmable Gate Array
FPS	Frames Per Second
GPU	Graphics Processing Unit
GUI	Graphic Users Interface
HAP	High-Altitude Platform
HD	High Definition
IML	Infrastructure Management Layer
IoT	Internet of Things
ITU-T	International Telecommunication Union Telecommunication standardization sector
KPI	Key Performance Indicators
KV	Key Values
KVI	Key Value Indicators
LEO	LEO
MAS	Multi-Agent System
MIMO	Multiple-Input and Multiple-Output
MR	Mixed Reality
NF	Network Function
NGMN	Next Generation Mobile Networks
NIC	Network Interface Card
OAM	Operations, Administration and Maintenance
P4	Programming Protocol-Independent Packet Processors
PDP	Programmable Data Plane

PoC	Proof of Concept
QoS	Quality of Service
RAN	Radio Access Network
RTK	Real-Time Kinematic positioning
RTT	Round-Trip Time
SDG	Sustainable Development Goals
SMO	Service Management Orchestrator
SNS IA	Smart Networks and Services Infrastructure Association
TRL	Technology Readiness Levels
UAV	Unmanned Aerial Vehicle
UE	User Equipment
uRLLC	Ultra-High Reliability & Low Latency Communications
VIM	Virtual Infrastructure Manager
VNF	Virtual Network Function
VR	Virtual Reality
XR	Extended reality

Executive Summary

The design of a new generation of mobile communications starts with the identification of the use cases that it will support. The telecommunications industry and academia are already at this task for the case of the 6G system. In a similar way, the DESIRE6G project undertakes a similar endeavour in this deliverable, looking for the use cases that will help to tailor the DESIRE6G system architecture and that will be used for showcasing and validating the project achievements according to its objectives and 6G vision.

We conducted a review of 6G use cases identified by different industry and innovation initiatives. The conclusion of this revision is that the definition of 6G use cases in the industry is still at an early ideation stage, without specific requirements and KPIs collectively agreed. However, some trends can already be identified such as the application of Digital Twins, new forms of remote interactions between humans, machines and/or the environment or the widespread use of robots. Many of them expected to have very demanding requirements in terms of latency, reliability, and availability.

This document outlines the DESIRE6G project's chosen use cases, a crucial step in designing an architecture aligned with its vision of a 6G system. The envisioned system integrates an end-to-end programmable data plane, a distributed multi-agent system, and a centralized service management and orchestration layer for supporting demanding requirements. The selection of the DESIRE6G use cases includes two main demonstrators: an AR/VR application with perceived zero latency with a focus on inspection operations (e.g. for emergency response situations) and a Digital Twin for robotic applications in industrial environments. These use cases are complemented with additional PoC ones, focused on intelligent image monitoring, cloud rendered gaming and latency sensitive robot control applications.

Key Contributions

For each of the selected use cases for the DESIRE6G project a set of functional requirements are specified. From those functional requirements, a set of requirements for the DESIRE6G architecture are specified as well as Key Performance Indicators (KPIs). Finally, a set of Key Value Indicators (KVIs) are also identified for the use cases selected.

1. Introduction

As has been the case for previous generations of mobile communications like 5G, the definition of the capabilities required by 6G has started with the identification of use cases that highlight the foreseen evolution in usage scenarios, and that reveal new needs and requirements that go beyond a regular upgrade of the previous generation, following the same design principles used in its inception.

This endeavour to identify the use cases that justify the evolution to the 6th Generation of mobile communications has already started and is led by industry organizations such as ITU-T, NGMN or the NextG Alliance along with other research initiatives. This process is still an on-going task, with the use cases currently being just sketched, without yet a consensus on detailed requirements and KPIs/KVIs emerging from these initiatives. However, several trends can already be inferred for the evolution of requirements, while new enabling technologies are being incorporated, stemming from the advances in certain fields such as AI.

This document details the use cases selected by the DESIRE6G project to be used as a reference for deriving the services that the DESIRE6G system architecture must provide, along with the system requirements and KPIs/KVIs. The selection of the use cases is done based on the work done so far from the relevant industry initiatives, while at the same time we are adapting them to the project scope and its committed innovations.

The structure of this document is the following:

- Section 2 makes a revision of the 6G use cases documented in different industry and research initiatives.
- Section 3 presents the main system components foreseen in the DESIRE6G vision.
- Section 4 introduces the selected use cases for the DESIRE6G project.
- Section 5 explains the methodology used to describe the selected reference use cases in Sections 6 to 10.
- Sections 6 to 10 describe each selected use case according to the methodology presented in Section 5.
- Section 11 collects the KPIs from the different DESIRE6G use cases and derives the requirements for the DESIRE6G system.

- Section 12 presents the impact on Sustainable Development Goals expected to be obtained with the DESIRE6G system by means of a selection of KVIs.
- Section 13 wraps up the contents and points to further work in the project regarding the use cases and DESIRE6G system requirements presented in this deliverable.

2. Related work on 6G use cases

2.1. NGMN initiative

NGMN has published in [1] its analysis of 6G use cases. 50 use cases were contributed by the different participants in NGMN, then grouped in 4 different classes, and eventually produce 14 generic use cases. The use case classes and use cases identified by NGMN are shown in the following tables.

Use case class	Use case	Observations
Enhanced Human Communication class	XR Immersive Holographic Telepresence Communication	Making use of various XR flavours (VR, MR, AR) and holographic representations
	Multimodal Communication for Teleoperation	Human multimodality information (i.e., audio, video, haptic, etc.) is transmitted for the purpose of some kind of teleoperation
	Intelligent Interaction & Sharing of Sensation, Skills & Thoughts	With the use of brain computer interfaces

TABLE 1: NGMN ENHANCED HUMAN COMMUNICATION USE CASE CLASS

Use case class	Use case	Observations
Enhanced Machine Communication class	Robot Network Fabric	Support for a safe, efficient, and collision-free traffic management of autonomous mobile robots, drones, AGVs, etc
	Interacting Cobots	Robots collaborating among them and with humans in precise and challenging industrial or personal tasks

TABLE 2: NGMN ENHANCED MACHINE COMMUNICATION USE CASE CLASS

Use case class	Use case	Observations
Enabling Services class	3D Hyper-Accurate Positioning, Localization, and Tracking	3D localization and tracking at centimetre level precision to support cobots
	Interactive Mapping	Connecting a large set of Digital Twins in the context of Smart Cities and Digitalised Factories
	Digital healthcare	Telemedicine enabled by body sensing devices and analytics in conjunction with enhanced connectivity by the use of XR technologies and multimodality information
	Automatic Detection, Recognition and Inspection	Use of sensing to automatically detect certain situations
	Smart Industry	The use of communication technologies for the different steps involved in the production process
	Trusted Composition of Services	Dynamic discovery and offering of services available to a customer

TABLE 3: NGMN ENABLING SERVICES USE CASE CLASS

Use case class	Use case	Observations
Network Evolution class	Native Trusted AI (AIaaS)	AI as a general service provided by the network either for its own purposes or by exposing the AI capabilities to external third-party user applications
	Coverage Expansion	Non-terrestrial coverage (e.g., satellite, high altitude platforms)
	Autonomous System for Energy Efficiency	Energy consumption optimization of the network and devices by the intelligent allocation of resources governed by AI/ML models.

TABLE 4: NGMN NETWORK EVOLUTION USE CASE CLASS

So far, NGMN has conducted only a high-level analysis of the proposed use cases without any specific requirements or KPIs per use case. Regarding technology components, the following ones are highlighted in the analysis conducted by the NGMN, many of them in line with DESIRE6G objectives:

- The need for extreme low latency and extreme high reliability for selected use cases.
- The use of combined sensing and communications.
- High accuracy contextual information (e.g., location, environmental, or body sensing data).
- Higher frequency bands for short range local coverage with high data rates and sensing.
- Trustworthiness of the data, maintaining privacy and security.
- Native and trustworthy AI (provided as an internal or external service).
- Convergence of computing and communication.
- Joint resource distribution and management.
- The need for energy efficiency.

2.2. Next G Alliance

The Next G Alliance has identified in [2] the applications that can influence the next generation of mobile communications technologies. The different NextG Alliance use cases for 6G are grouped into four areas, shown in the following tables.

Use case class	Use case	Observations
Network-Enabled Robotics and Autonomous Systems	Online Cooperative Operation among a Group of Service Robots (SOBOTs)	Working in various every day or industrial tasks
	Field Robots for Hazardous Environments	Robots used for mission-critical tasks in hard-to-access and dangerous locations

TABLE 5: NEXT G ALLIANCE NETWORK-ENABLED ROBOTICS AND AUTONOMOUS SYSTEMS USE CASE CLASS

Use case class	Use case	Observations
Multi-sensory Extended Reality	Ultra-Realistic Interactive Sport – Drone Racing	Players fly drones through a racetrack and grab digital objects
	Immersive Gaming/Entertainment	Interacting with virtual special characters (e.g., Christmas characters), immersive gambling (e.g., a virtual casino experience), or eSports.
	Mixed Reality Co-Design	Several designers (remote or co-located) collaborate on a product design in an MR environment
	Mixed Reality Telepresence	Someone is made to appear to be in a certain location while being in another by means of MR
	Immersive Education with 6G	The benefits that immersive communications can bring to the education experience, enhancing it and improving student engagement
	High-Speed Wireless Connection in Aerial Vehicle for Entertainment Service	Examples are in-flight remote video streaming, videoconference and internet gaming services, and also in-flight local wireless networking

TABLE 6: NEXT G ALLIANCE MULTI-SENSORY EXTENDED REALITY USE CASE CLASS

Use case class	Use case	Observations
Distributed sensing and communications	Remote Data Collection	Data collection from IoT devices in remote or rural areas through the use of 3D NTNs (including UAVs, HAPs, and satellites)
	Untethered Wearables and Implants	IoT devices equipped with native 6G cellular connectivity.
	Eliminating the North American Digital Divide	Achieving digital equity goals in North America
	Public Safety Applications	With the use of high-resolution video
	Synchronous Data Channels	Delivering of data with full synchronization for applications with extreme time sensitivity
	Health Care – In-Body Networks	Use of in-body sensing and analytics in conjunction with wide area connectivity

TABLE 7: NEXT G ALLIANCE DISTRIBUTED SENSING AND COMMUNICATIONS USE CASE CLASS

Use case class	Use case	Observations
Personalized User Experiences	Personalized Hotel Experience	Automated guest check-in and check-out, automated room service, virtual hotel concierge and privacy assurance
	Personalized Shopping Experience	Immersive virtual store experiences

TABLE 8: NEXT G ALLIANCE PERSONALIZED USER EXPERIENCE USE CASE CLASS

In terms of requirements Next G Alliance provides a list of requirements for each of the use cases. However, most of the times actual performance figures are not provided. Instead , a list of technologies are described that will play a role in supporting the use case. The following is a summary of these requirements and technologies identified by the Next G Alliance in its different use cases:

- Ultra-low latency communications.
- Motion-to-Photon (MTP) delay below 20 ms.
- High downlink and uplink data rates.
- Transmission of high-definition pictures or films, with a data rate of up to 4Gbps, both from urban and rural areas.
- Rapid re-establishment of connections in case of a failure.
- Very high level of clock synchronization accuracy.
- The need for security and privacy protection of user data.
- Mobility at vehicular speeds.
- Interworking and seamless mobility between terrestrial and NTN networks.
- Very high communication service availability and DL/UL packet reliability.
- Position accuracy and object-sensing accuracy - reaching centimetre levels.
- High levels of localization and mapping.
- Extreme Massive Machine-Type Communications (mMTC) support.
- Enhanced Mobile Broadband (eMBB) for users in remote areas or disaster areas.
- Extreme Coverage for users in remote areas.
- AI-assisted decision-making.
- Support for edge computing.
- Situational context awareness.

2.3. ITU

ITU-T, by means of its Focus Group on Network 2030 has analysed the use cases driving the evolution of networks. Two technical reports [3] [4] by the FG-NET2030 were produced in 2020, identifying a total of 12 use cases, which in fact are in themselves use case classes.

Use case	Description
Holographic Type Communications	Fully immersive experiences that require the transmission of 3D images through the network.
Tactile Internet for Remote Operations	Real time control of remote infrastructure in fields such as Industry 4.0 (real time factory monitoring and control) or telemedicine (e.g., remote surgery) incorporates haptic feedback from a human operator, typically in addition to immersive audio-visual feeds. incorporates haptic feedback from a human operator, typically in addition to immersive audio-visual feeds
Intelligent Operation Network	Use of AI to detect network impairments, pinpoint root causes of alarms and execute automatic recovery procedures
Network and computing convergence	Use of computing resources inside the network itself in addition to the cloud and use of computing aware orchestration capabilities, with fast routing and rerouting of traffic flows and computing tasks to the appropriate site, depending on the current conditions
Digital Twins	Use of digital representations of physical entities for improving situational awareness and a better response (e.g., physical asset optimization or predictive maintenance in a Digital Twin City).
Space Terrestrial Integrated Networks	Use case focused on providing an integration of terrestrial and LEO satellites in an integrated Internet framework
Industrial IoT with cloudification	Automatic operation and control of industrial processes to minimize human intervention
Huge Scientific Data Applications	Support of large-scale scientific applications such as astronomical telescopes and particle accelerators
Application-aware Data Burst Forwarding	Advocating he need to evolve networks from packet-based forwarding to burst forwarding to improve the efficiency of the network and computing resources used

TABLE 9: ITU-T FOCUS GROUP NETWORK 2030 USE CASES

Use case	Description
Emergency and disaster rescue	The need to globally deploy the sensor infrastructure and the required Intelligence to react and coordinate the evacuation of areas affected by one or several emergencies
Socialized Internet of Things	Collaboration of IoT devices from different platforms or providers to achieve a certain task (e.g., logistics delivery) by means of establishing social relationships between them
Connectivity and sharing of pervasively distributed AI data, models, and knowledge	intelligent IoT devices taking an active role in AI processing, not just as collectors of raw data

TABLE 9: ITU-T FOCUS GROUP NETWORK 2030 USE CASES (CONT.)

2.4. Hexa-X EU project

In the 2030s, the emergence of 6G technology is expected to unlock a multitude of new use cases driven by societal needs. These use cases will offer not only improved implementations of existing services but also novel approaches to mobile app design.

The Hexa-X project has identified several potential use cases for 6G technology, which can be grouped into six distinct families based on the challenges they address or the technological capabilities they harness [5]. These use cases serve as examples of the anticipated functionalities that 6G networks will provide in 2030, influencing the requirements and highlighting the need for new capabilities in the future. The discussion around the potential applications of 6G has drawn input from both the corporate and academic communities, reflecting the diverse perspectives on the possibilities offered by this next-generation technology [6].

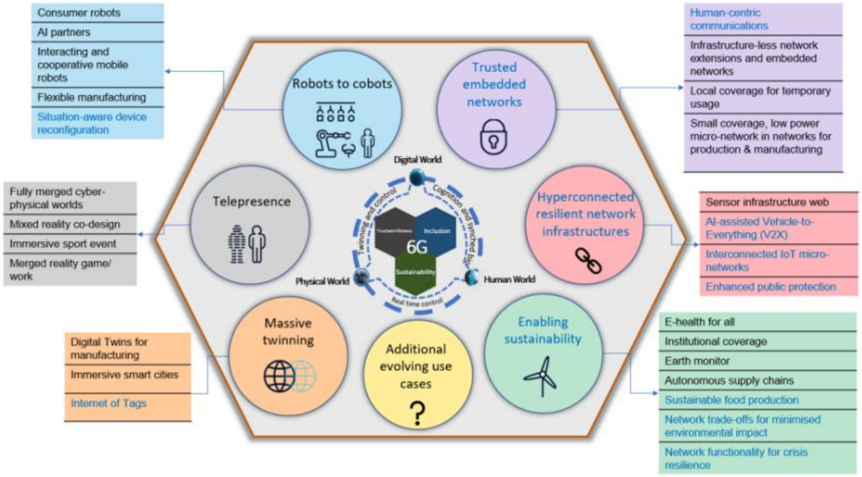


FIGURE 1: HEXA-X USE CASE FAMILIES [7]

The shift from traditional robots to **collaborative robots** (**cobots**) involves adopting robots designed to work seamlessly with humans in various applications, emphasizing industrial productivity, safety, and efficiency. Cobots extend their utility to domestic environments, aiming to execute tasks collaboratively with human employees for a more natural relationship. Key requirements for robot to cobot use cases include safety, human-robot interaction, flexibility, productivity, real-time data sharing, remote control, and dependability. Ensuring low latency for real-time interactions, high reliability to prevent disruptions, and effective security measures are crucial. Good signal strength and proper coverage contribute to stable communication, while scalability supports expanding cobot networks. Power efficiency enhances battery-powered cobots' operating duration, and measures to reduce interference and maintain compatibility improve communication efficacy, with network resilience ensuring continuous operation despite failures or interruptions.

Immersive **telepresence** allows individuals to virtually interact using all senses, fostering seamless engagement anytime and anywhere. This technology extends beyond human-to-human interaction, enabling engagement with virtual worlds and physical and digital objects. A notable application is the "Fully merged cyber-physical worlds," where Mixed Reality and holographic telepresence serve as vital communication tools for daily life. To ensure a flawless telepresence experience, high data rates, low latency, and reliable connectivity are crucial. Emphasizing connected intelligence and trustworthiness supports long-term sustainability. Immersive telepresence not only enhances user experiences but also aligns with the United Nations Sustainable Development Goals by reducing the need for travel and promoting global environmental responsibility through sustainable remote collaboration.

Massive twinning, the widespread adoption of Digital Twin (DT) concepts across industries, is poised to create a comprehensive digital representation of various sectors, such as manufacturing, urban development, transportation, logistics, entertainment, digital health, military, and public safety. The critical need for significant data transfers, low latency, high reliability, and enhanced capacity makes the use of DTs crucial in these domains. Long-term, globally-reaching solutions are essential for handling extensive data flows and achieving synchronized and accurate digital representations. This process involves precise physical modelling, advanced insights, experimentation, and substantial data flow, with high-resolution 4D mapping and real-time analytics connecting the virtual and physical worlds.

The **Enabling Sustainability** use case family focus in 6G aims to bridge global disparities by providing widespread access to digital services and implementing climate-friendly infrastructure. 6G's unique capabilities offer opportunities for sustainable growth, utilizing data collection and global responsiveness. Specific use cases include the Earth monitor for environmental indicators, E-health for universal healthcare access, Institutional coverage for performance in underserved areas, and the Autonomous supply chain to reduce waste using AI/ML.

Trusted embedded networks use case family focuses on scenarios requiring high trustworthiness in localized sub-networks. These environments demand exceptional reliability, availability, resilience, and stringent security, particularly in settings like precise healthcare, where in-body devices connect autonomously to a local center to ensure confidentiality. Infrastructure-less network extensions enable coverage expansion beyond the network's edge through techniques like multi-hop self-relaying. These use cases emphasize the significance of trustworthiness in local networks and their diverse applications.

Hyperconnected resilient network infrastructures in 6G employ AI algorithms to improve automobile services. These algorithms process extensive data from various sources in metropolitan areas for real-time monitoring and dynamic traffic optimization. The resulting digital representation of traffic scenarios enables coordinated network nodes to enhance safety, reduce congestion, and support sustainable mobility. Network nodes collaborate to dynamically regulate traffic across urban areas, aiming to reduce overall volume. This use case family encompasses AI-assisted Vehicle-to-Everything, Interconnection IoT micro-networks, and enhanced public safety [8].

2.5. Academic research on URLLC and towards extreme URLLC

New and emerging services and applications demand lower latency and enhanced reliability at an unprecedented scale and are much stricter than those set for 5G URLLC. For example, high-precision robot control and autonomous vehicles cannot afford millisecond latency [9] while factory automation over wireless links demands sub-ms E2E latency [10]. Moreover, deployments need to be scalable in the sense that they must simultaneously support massive connections and high data rates, unlike 5G URLLC designs that target sparse deployments and short packet transmissions [11]. In this respect, one has to go beyond 5G URLLC to enable critical applications including AR/VR, Digital Twins, robotics, and online gaming, among others. This in turn stimulated a great interest in the academic community to conduct research not only on URLLC but also beyond URLLC (or extreme URLLC) [12], [13] as advocated by the DESIRE6G, where state-of-the-art machine learning techniques, among others, are substantially integrated into the overall architecture so that the designs are more proactive than reactive.

Existing research directions have already dealt with URLLC enablers at different layers of the communication system. As such, in the physical layer, advanced coding and modulation schemes are investigated to improve spectral efficiency and error correction capabilities, critical for reliable and low-latency communication [14] [15] [16] [17]. Utilizing MIMO techniques at both the transmitter and receiver ends has been a classic way to improve reliability and spectral efficiency, especially in challenging environments [18] [19] [20]. In parallel, many recent works of URLLC fall in the direction of synchronization and clocking. It is identified that precise timing synchronization is critical for maintaining low-latency communication, especially in applications where multiple devices need to coordinate their actions [21] [22] [23] [24]. Research in the direction of low-latency radio access explores techniques like grant-free transmission and grant-based schemes with minimized scheduling delays to reduce the time it takes to establish a connection and start transmitting data [25] [26] [27]. Edge computing benefits from placing computational resources closer to the end-users at the network edge to significantly reduce processing delays, enabling faster response times [28].

Some of the research on URLLC such as [29] [30] [31] [32] are centred on network slicing to allow for the creation of virtual, isolated networks within a shared physical infrastructure, enabling customization of network behaviour to meet specific requirements. Machine Learning (ML) techniques to enable URLLC have been explored by many researchers essentially to predict communication network behaviour, proactively identify potential issues, and optimize resources accordingly [33] [34]. In parallel, research in network function virtualization (NFV), that decouples network functions - traditionally performed by dedicated hardware appliances - from the underlying physical hardware, offers greater flexibility and programmability in network operations, enabling dynamic adjustments to meet URLLC requirements [35].

The importance and inevitability of making a comprehensive adjustment of the existing theoretical and practical developments of existing URLLC to new paradigms has been envisaged [12] [13]. The researchers in [12] [13] highlight that achieving URLLC beyond 5G recommendations necessitates a departure from conventional expected utility-based methodologies that hinge on average values. Instead, they advocate for developments aiming at proactive decision-making integrated with state-of-the-art machine learning techniques. The authors propose three fundamental pillars based on which the new developments be envisioned: (1) the incorporation of recent advancements in machine learning to enhance the convergence and reliability of data-driven predictions; (2) the integration of both radio frequency (RF) and non-RF modalities to model and address rare events while maintaining spectral efficiency; and (3) the emphasis on. joint communication and control co-design, a departure from the communication-centric approach of former URLLC approaches. Furthermore, they outline specialized tools and methodologies to facilitate the implementation of such developments. The academic research domain pertaining to URLLC is continuously expanding to address the stringent demands of emerging applications. Therefore, it deserves additional in-depth investigation.

3. DESIRE6G System Components

Figure 2 shows the envisioned components of the DESIRE6G system vision. The network consists of topologically separated DESIRE6G sites, including local HW and compute resources running Network Functions (NFs) necessary for the execution of the network services and Application Functions (Afs) required by the (application-specific) services. Each DESIRE6G site has almost identical setup with slight variances based on necessity, e.g., the sites supporting Radio Access Network (RAN) functionality are equipped with sufficient hardware entities and/or non-programmable (static) functions. All of which are still considered NFs by the system. Also note that the User Equipment (UE) might also be able to run a stripped-down version of the DESIRE6G stack using its own hardware and software stacks. This is a big difference compared to existing UE approaches and it makes end-to-end service control possible. Of course, legacy UEs can still use the system as today attaching to some “edge-to-edge” service, e.g., normal Internet access.

Between the DESIRE6G sites there can be non-programmable elements. These can be controlled by Software-Defined Networking Controllers (SDNCs) or by traditional routing protocols. The minimum requirement is that the DESIRE6G infrastructure must understand the reachability of the other sites from each given site (e.g., IP addresses of the other site’s gateway).

The main components are the following:

- **Service Management and Orchestration (SMO)**: Similar to existing specifications (i.e., NFV orchestrator for ETSI MANO), the SMO is responsible for end-to-end service life-cycle management, including service provisioning and deployment, network slice management and network optimizations. It contains several modules responsible for these different tasks and it is the main interface towards the external world.
- **Multi-Agent-based network intelligence System (MAS) and telemetry**: MAS implements distributed network intelligence closer to the physical infrastructure, as it is responsible for receiving service-specific monitoring information and fine-tuning the network and compute resources. It configures and uses a pervasive telemetry system to receive service specific KPIs, e.g., by monitoring end-to-end latency for latency-sensitive or latency-critical services.

- **Programmable Data Plane (PDP) layer including the Infrastructure Management Layer (IML) and the HW/SW specific implementations of the NFs**: The E2E Programmable Data Plane is employing NFs to carry out the logic of the selected service. NFs contain a Control Plane component (NF-CP) and the packet processing Data Plane logic (NF-DP). Note that at this level the main role of NF-CP is to configure and update the objects (e.g., tables, registers, etc.) in the corresponding NF-DP. These are separated by the IML responsible for transparent scaling, acceleration, and deployment, i.e., it is the bridge between the logical and the physical network function. IML hides the implementation and deployment details of NF-DP from NF-CP by providing a simple unified view of the data plane. For example, even if NF-DP is vertically or horizontally disaggregated into multiple data plane programs running on different HW/SW targets, IML ensures that NF-CP only sees a single NF-DP instance and IML handles the complexity of managing the disaggregated packet processing components.

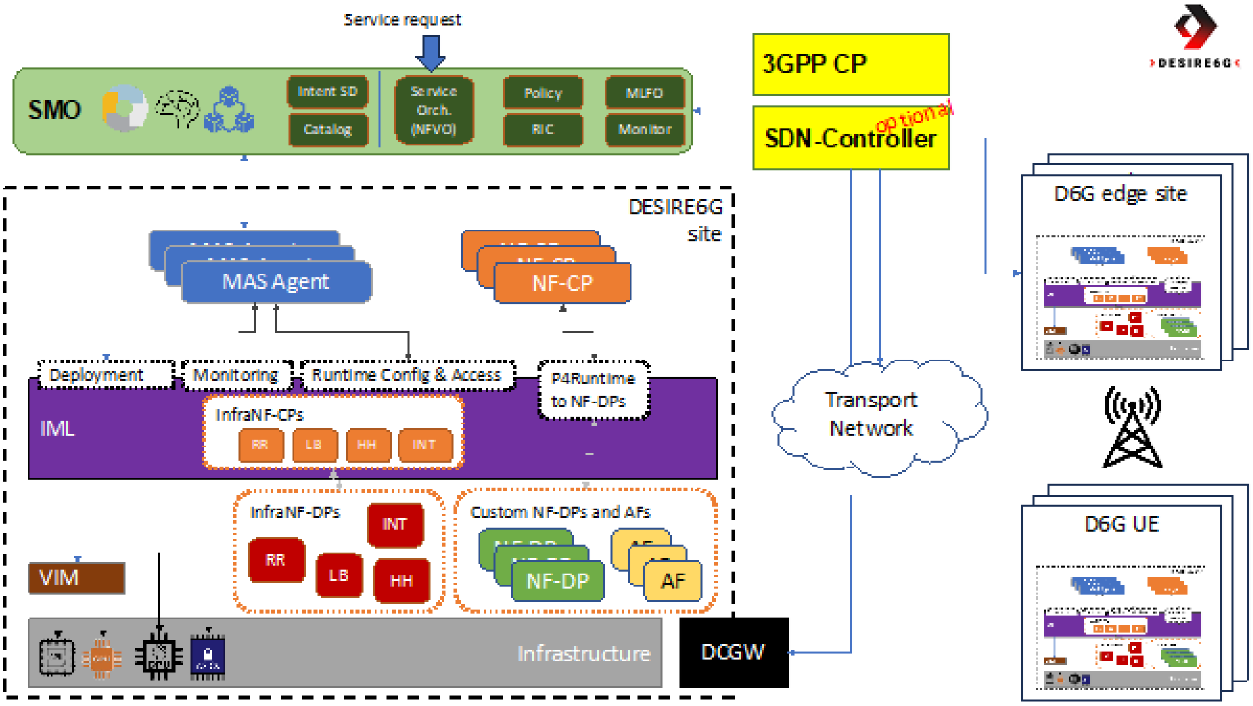


FIGURE 2: DESIRE6G SYSTEM COMPONENTS

4. DESIRE6G Use Cases

DESIRE6G project has selected several use cases to be used as reference for the definition of an architecture incorporating the technical innovations committed in the project description of work, around the system components presented in the previous section. These use cases will be used for showcasing the proposed architecture and project innovations in demonstrators and PoCs throughout the rest of the project.

The project has selected **2 main demo use cases**. The first demo use case is an **AR application with perceived zero latency**. Such a use case is very much in line with many similar 6G use cases in the reviewed industry initiatives (Section 2) focusing on new ways of interaction and making use of AR/VR. Such an AR use case can find an application in several fields, for example as a tool for emergency response systems or for diverse cases of remote maintenance operations.

The second demo use case is a **Digital Twin** for controlling robots in an industry environment. As can be noted in section 2 the use of robots being remotely operated in a smart industry context is another popular theme in the different industry initiatives, as well as the use of digital twins to reproduce digitally the physical world. The operation of such robots is an example of cyber physical control applications in the industry vertical domain.

In addition to these 2 main demo use cases, several PoC use cases are also proposed. The **latency sensitive robot control** focuses also on the control of robots remotely, but without the intervention of a digital twin in this case. The **intelligent image monitoring** is another PoC use case aimed at an industrial environment but focused on the monitoring aspects of such a critical environment instead of the robot control aspects. Finally, a PoC of a **cloud gaming service** is included to extend the value impact of the DESIR6G system to the entertainment vertical domain.

In addition to the DESIRE6G use cases, other verticals and use cases that share the same kind of requirements would also be positively impacted by the DESIRE6G innovations.

5. Use Case Analysis Methodology

In order to characterize the selected use cases that will act as a reference for the architecture and to showcase the innovations envisioned by the DESIRE6G project, a common methodology to describe the use cases is applied in sections 6 to 10 of this document.

Each use case description will be comprised of the following:

- **High-level description** of the use case.
  This high-level description is provided from the point of view of the application that is implementing it, leaving out to a large extent specific implementation choices at the architecture level of the underlying DESIRE6G system supporting the use case. It focuses mainly on the objectives of the use case, and on the functional modules specifically pertaining to this use case (e.g., end users and any specific service elements required by the use case) and the interactions between them at the application level.
- A **characterization** of the use case in terms of:
  - **Functional requirements.**
  - **KPIs**; known KPIs of the use case.
- **Technical components** of the use case. These are the technical components of the use case, and the implications in terms of the required infrastructure to support them as well as the data that needs to be extracted and analysed from the DESIRE6G system for the use case to work. In general, these are not the technical components of the underlying DESIRE6G architecture.
  - **Workloads.** These implement the functional modules that are specific to the use case. In most cases, these workloads belong to the application domain and are not a functional part of the underlying DESIRE6G system. However, they can be hosted by the DESIRE6G system in some infrastructure destined to host this kind of application functional modules.
  - **Infrastructure.** It is the infrastructure required for the execution of the use case workloads. This infrastructure could be provided by the DESIRE6G system (e.g., as an x86 Edge Cloud computing platform or as an in-network computing platform), or it could be

    the infrastructure of an external service platform that connects to the DESIRE6G system (e.g., an external x86 Edge Cloud computing platform or a caching server platform).
  - **Devices/terminals.** Any kind of device or terminal that belongs to the customer premises and that is required by the use case. Some use cases are agnostic to the end user devices taking part in the use case, but others imply a specific type of device (e.g., AR/VR headsets).
  - **Data analytics.** The data that is required to be analysed at the DESIRE6G system level to fulfil the KPIs of the UCs (latency, packet loss, etc.) by reacting to deviations experienced. It imposes a requirement on the DESIRE6G system to be capable of extracting the appropriate metrics.
- **Other considerations.**
  - **Technology gaps.** Any technology gap in the state of the art that justifies the use case to be included as a reference use case for the DESIRE6G system.
  - **Required datasets.** Any kind of dataset that the use case requires or could potentially use to optimize its context. Datasets can be synthetically generated (e.g., by means of simulations), experimentally gathered (e.g., from the data analytics obtained from use case PoCs) or any other kind of relevant context information (e.g., network topologies, traffic matrices, etc.) for evaluation of the use case (e.g., techno-economic studies). The source of the datasets could be external from public repositories (e.g., other projects, reference datasets) or internal (coming from the project partners or generated internally in the project testbeds).
- **Relevance for DESIRE6G.** Why the use case is relevant for the DESIRE6G project.
- **Mapping to DESIRE6G envisioned architecture.** A preliminary mapping of the use case to the DESIRE6G envisioned architecture.

6. AR/VR Use Case

6.1. Description

This use case has the goal to test an "Augmented Reality/Virtual Reality (AR/VR) in a drone-human operator cooperation scenario" aiming surveillance and inspection applications. The application aims to exploit the superior mobility of a camera-equipped drone to grant enhanced vision to human operators wearing an AR headset. The drone will perform inspection of the area of interest, collect images and send them to an edge computing node to perform data analysis and object detection. Elaborated data will be sent to the operator's headset. The application will leverage 6G communications to offer improvements in terms of bandwidth, reliability, and perceived zero latency.

The app is distributed in several functional modules that are placed at different locations, i.e., the source nodes, the edge computing nodes and the headset. Indicatively, source nodes (namely, the drone) will collect information and send it to the edge computing node, which will perform data processing necessary for providing an immersive experience to the human operator: processed information will be sent to the operator's headset, then, granting an augmented perspective of the area under survey. The application will also allow the operator to control the drone's operations, e.g., select the cameras' direction and/or focus on specific objects.

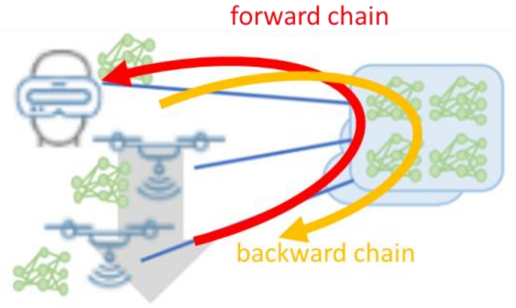


FIGURE 3: AR/VR APPLICATION FOR PERCEIVED ZERO LATENCY

The application will exploit forward and backward chains to perform the communications among the functional modules, as shown in Figure 3.

Forward chain

The application receives several video streams, generated by the cameras of different mobile (e.g., drone) and/or fixed (e.g., security camera) devices. Each camera provides video streams that can be sent to the edge computing node for object recognition, classification, and AR augmentation, using AI-models. The operator, equipped with the AR headset will have a wide-angle real time video with enhanced sight of the area of interest. Specific objects will be automatically recognized and augmented with 3D reconstruction, zooming functions and specific information.

Backward chain

Users, equipped with AR Headset, have the freedom to select and change the visual parameters of the AR scene. They may use the headset in transparent mode, maintaining their own point of view or switch to the camera view to get better visual on the scene or to get closer to specific objects. Thus, using the interactive Graphical User Interface (GUI) of the Headset, they will send interactive commands to the source nodes to change/tune camera angles/zoom/perspective of one or more cameras. The final impression is a natural perspective change as the user is effectively moving autonomously within the scene.

The pictures in Figure 4 show the high-level description of the application. The use case leverages on this architecture to provide steady data streaming between the operator's headset and the drone, with perceived zero latency. The figure also shows how the edge computing node handles the collection of significant and heterogeneous metrics through cameras mounted on drones, performing AI-based processing and real-time data augmentation. In fact, more than one edge may be involved for reliability or optimization purposes, providing application function interactions or replicas (e.g., using alternative serverless chains). Finally, augmented data will be sent to the operator's headset.

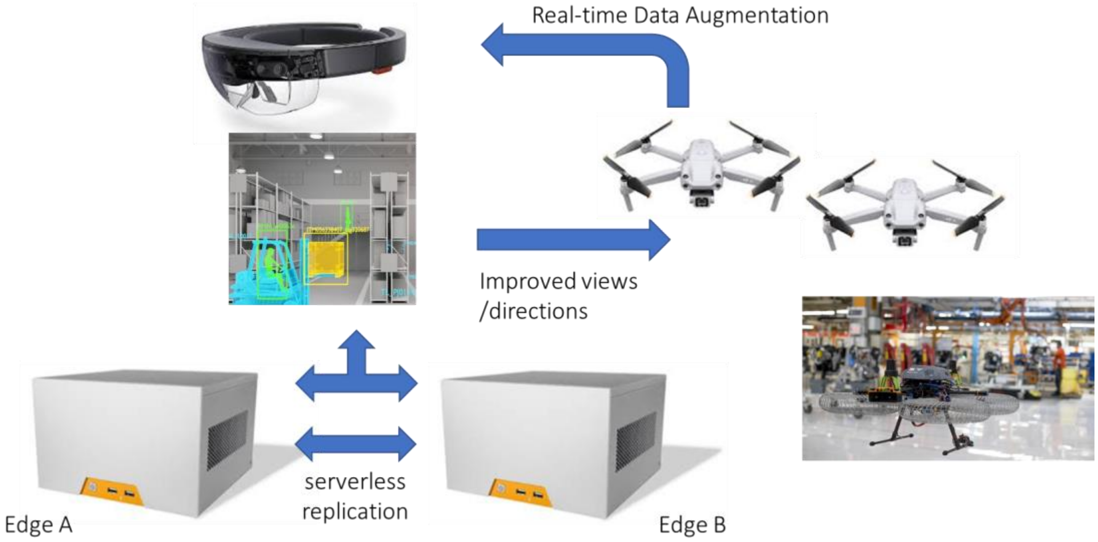


FIGURE 4: AR/VR APP HIGH-LEVEL DESCRIPTION

Figure 5 shows the function chain of the application, including the first step detection and the data/video fusion for the headset, and the final feedback commands to the cameras. The mobile source nodes and the headset are connected by means of wireless connectivity to the edge nodes and a significant percentage of latency is due to wireless connectivity including access network processing (RAN functions).

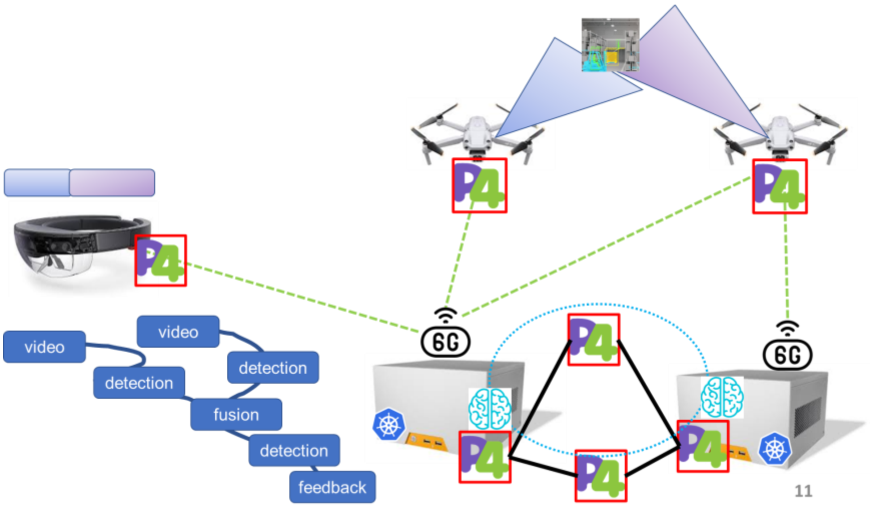


FIGURE 5: CHAINED APP AND DEPLOYMENT USING DATA PLANE PROGRAMMABILITY

Data plane programmability is highly desirable in this use case. Besides using programmable devices in the edge network domain, implementing the wired and wireless network functions, the mobile source nodes (i.e., the drones) will also be equipped with such programmability, allowing the collection and the transmission of telemetry metadata especially targeted for latency monitoring.

6.2. Characterization

6.2.1. Functional Requirements

Functional requirement	Description
Video processing and rendering	The application should be able to process and combine multiple video streams from different sources in real-time to make 3D object reconstruction possible.
Tracking and mapping	The application should be able to track the operator's position and movements in real-time, as well as map the physical environment to the virtual environment.
Object recognition and tracking	The application should be able to recognize and track objects in the physical environment and overlay relevant information or graphics on top of them.
User interaction and input	The application should allow operator to interact with the virtual environment through natural gestures, voice commands, or other input methods.
Data synchronization and communication	The application should enable bidirectional communication between the operator's headset and the virtual environment, allowing for real-time data transfer and synchronization.
User authentication and security	The application should provide secure authentication mechanisms to ensure that only authorized operators have access to the virtual environment and data.
Performance optimization	The application should be optimized for low latency, high bandwidth, and efficient use of computing resources to ensure a smooth and immersive experience for operators.
Resiliency	The application should be resilient, meaning that should grant stable and continuous communication, in any possible application scenario for the use case. The resiliency should support dynamic modification of the application chain workflow, dynamic assignment of resources at the radio, packet and compute nodes, and dynamic traffic steering.

TABLE 10: AR/VR USE CASE FUNCTIONAL REQUIREMENTS

6.2.2. KPIs

KPI	Value
AR/VR app end-to-end latency (unidirectional)	5ms for the network delay <20ms total (ideal) <50 ms total (tolerated)
AR/VR app throughput	Depending on the video features (resolution, fps, field of view). Camera streams from UAV and/or fixed camera: 50-100Mbps (4K 60fps HEVC265). Streams to the Headset: min 130Mbps – max 960Mbps
Re-optimization time (AI-based)	<100ms
Reliability	99%
Scalability	Number of drones per service: 1/10 Number of users per service: 100

TABLE 11: AR/VR USE CASE KPIS

In an AR/VR application with multiple video sources and bidirectional communication, low latency is crucial to ensure a smooth and seamless experience for users and to prevent cyber dizziness. With multiple video sources, the application needs to process and combine video streams in real-time. Similarly, bidirectional communication headsets require low latency to ensure that users' actions and movements are accurately captured and reflected in the virtual environment.

The operator's headset and the other cameras need to refer to the same reference system in order to provide precise object detection and labelling: various cameras may refer to the same reference system through calibration procedures or using navigation technologies that refer to a common origin, such as the Real Time Kinematics framework (RTK).

To achieve a seamless and natural user experience for AR/VR applications, the overall end-to-end latency should ideally be below 20ms. The literature suggests ideal 3-20ms and tolerated 20-50ms ranges to assure a perceived real time experience and prevent cybersickness [36] [37]. This latency includes all components of the system, including the video encoding and decoding, network transmission, and processing on the headset or device. Achieving such low latencies can be challenging, particularly for wireless networks. However, it is possible to use techniques such as time warp or late latching to help mitigate the impact of latency on the user experience. Time warp is a technique used in VR applications that involves predicting the user's head movement and rendering the next frame of the virtual environment in advance to reduce the perceived latency. This technique can help to mask the effects of network latency and provide a smoother and more immersive experience for the user. Late latching, on the other hand, involves delaying the display of a frame until the latest possible moment to reduce the perceived latency. This technique is commonly used in AR applications and can help reduce the latency of the visual feedback provided to the user.

Overall, for AR/VR applications that involve human interactions, and especially for AR, the latency threshold is much lower than for traditional video conferencing or collaboration, and achieving low latency is essential for providing a seamless and immersive user experience.

6.3. Technical Components

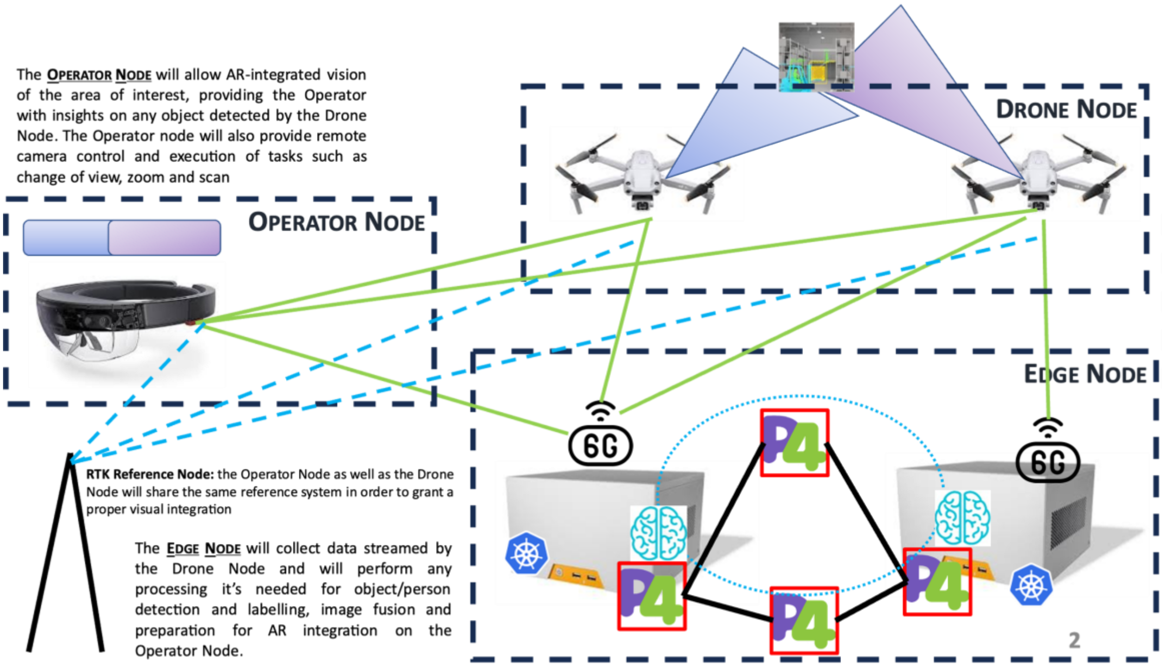
The following technical components are envisioned for the deployment of the use case.

Category	Technical components
Communication	• Wireless (enhanced 5G). • Edge SDN switches domain. • DPU at the edge for workload accelerations.
Computation, Placement and Monitoring	• Serverless function chain (FaaS platform) at the edge. • CPU+GPU resources at the edge for image processing and data fusion. • Network and IT latency monitoring to assure end-to-end QoS.
Tracking	• RTK devices both on headset and drone.
Fixed Devices	• P4 switches (SW and HW), GPU, FPGA, DPU, 5G RRU, Dome Cameras, edge micro data centres.
Mobile devices	• Headset equipped with radio interface, feedback commands, RTK tracker and camera for transparent mode. • UAVs equipped with cameras (full HD or 4K), radio interfaces and RTK tracker. • Devices augmented with internal data plane programmability backend to add user/app metadata.

TABLE 12: AR/VR WITH PERCEIVED ZERO LATENCY FORESEEN TECHNICAL COMPONENTS

6.3.1. Workloads

Workloads included in the Use Case are depicted in the following figure, each of the with a proper description of its main functional role within the architecture.



The **OPERATOR NODE** will allow AR-integrated vision of the area of interest, providing the Operator with insights on any object detected by the Drone Node. The Operator node will also provide remote camera control and execution of tasks such as change of view, zoom and scan

RTK Reference Node: the Operator Node as well as the Drone Node will share the same reference system in order to grant a proper visual integration

The **EDGE NODE** will collect data streamed by the Drone Node and will perform any processing it's needed for object/person detection and labelling, image fusion and preparation for AR integration on the Operator Node.

FIGURE 6: AR/VR APP WORKLOADS

6.3.2. Infrastructure

The AR application need specific requirements to be satisfied and the integration of a proper drone motion control with an AR multicamera system is required.

The employed drones need to be able to bring the camera (or cameras) around the area of interest: controlling the drones and the cameras will be performed through different channels for a safer and faster application. Camera modules latched on drones will provide software components to record, and stream images to more powerful computing resources. Scanning, detection, storing and organization of any significant data will be performed by the Edge Node, into NIC-powered stations, while communication between nodes (i.e. the drone, the computing station, and the main station) will be performed through P4 programmable datapaths.

The Operator will be provided with an AR/VR headset representing another node of the system and virtually the main operating station: the Operator will be able to communicate with camera systems, executing specific tasks such as change of view, zoom in/out, and scanning of specific objects. Communication between the operator and the drone-mounted cameras will be enabled by P4 channels to grant stability and celerity.

Drone motion-related control will be deployed to another communication line so that it will not have to share its traffic with other data, and it will allow direct control from the Drone Operator to the device, enabling motion in the area of interest independently on the task performed by the cameras.

In other to grant an immersive AR/VR experience it is necessary to provide perceived real-time remote control and communication, which is possible to achieve thanks to the support of the Edge Node computing power. The Edge Node provides computing capabilities able to lighten the other nodes of the network, in order to offload time-sensitive processing from the drone as well as the headset.

The Edge Node will rely on wired connectivity to the main station (potentially to the headset), allowing for fast transmission of elaborated data. The Operator is not supposed to move from the main station, so being cabled would not represent any kind of inconvenience. The Edge Node will rely on switches and wireless connectivity with the drone and its cameras.

6.3.3. Devices/terminals

This use case will involve the use of an AR headset as end-user terminal and a drone equipped with cameras to scan the area of interest. Drones will be capable to move independently from the user.

A serverless framework will provide resources for communication between users and drones and for data analysis. The network will consist of radio controllers (e.g., RIC), and any other element necessary to provide enough computational power to grant perceived zero-latency in communication and data analysis.

6.3.4. Data analytics

The main data analytics considered for this use case is the application delay in all its component that needs to be collected and monitored during the application runtime. Delay analytics management is not part of the application itself. The application may utilize buffering and scaling options in case of high delay. However, analytics and the joint application and network re-optimization framework has to consider the relevant delay constraints of the end-to-end application.

The whole network is organized in an upstream flow of information, from the cameras to the operator, passing through the edge node and a downstream flow from the operator to the cameras. In upstream, the drone and its cameras transmit sensor data, drone position in the RTK (Real Time Kinematics) system, camera orientation and camera data flows. Each transmitted packet needs to associate images with an estimate of the drones' position in the area of interest and with respect to the headset. These upstream packages will be sent to the edge node to be processed. More information will be sent to the main node (namely, to the operator's headset), consisting also in any possible detected object label and position in the RTK system. For what concerns the whole system response time for providing information on the area of interest, the upstream flows could tolerate a latency ideally not higher than 20ms.

In downstream, the operator may interact with the AR scenario, requiring specific actions from the cameras to be performed. This control flow is lighted than the upstream since it communicates data such as position, orientation, and task (such as zoom in/zoom out) information that require low control cycles. The latency may vary from few ms to up to 50ms (not shown in the KPI table), depending on the real-time requirements of the tasks.

6.4. Other Considerations

6.4.1. Technology gaps

AR/VR applications often demand extremely high data rates. The design of communication networks, data analysis, and streaming to meet these data rate requirements is an ongoing area of research [37].

The specific network requirements for AR/VR primarily depend on the individual use cases or applications. Numerous studies have focused on VR implementations, emphasizing the delivery of high-quality, low-latency downlink video streams [38]. AR applications not only involve the accurate placement of virtual content but also need seamless user interaction with it, and this would require real-time and precise analysis of the physical environment.

Given the high demanding processing and hardware requirements of multiple video streams manipulation (including AR-mapping algorithms and adaptation to the headset), motivates offloading these algorithms from the device. So, there is a gap in understanding where and how individual algorithms should run and what their offloading requirements are. This study aims to investigate the proper distribution of data analysis and communication within an enhanced network to achieve perceived zero-latency for the end-user.

This Use Case will tackle on hardware-accelerated communication to enhance AR, reaching new level of interaction between the user and the connected system, that are still matter of research. Moreover, AI-augmented object detection from peripheral cameras shared reference will grant the user a versatile way to quickly scan unreachable wide areas, gaining not only images but also valuable information about the surroundings.

Most of the AR/VR applications have focused on the visual modality, overlaying virtual objects on the real world seen through the live camera feed on the user's screen. This use case aims to identify real world objects on the screen, tracking them, and then augmenting the scene with artificial information and labels. Tracking will involve estimating the correct 2D or 3D world coordinates for proper placement of augmentations in the scene.

6.4.2. Required datasets

The AR/VR user case may be supported by any kind of multicamera-videos datasets realized using drones. An example may be the VisDrone Dataset available at https://github.com/VisDrone/VisDrone-Dataset. These kinds of data would be employed to test object detection and labelling algorithms and to verify how the Survey Operator could visualize acquired information on the headset.

Any action performed by the user to control the cameras will need to be tested using newly acquired data since it strongly depends on real-time response and interaction between the Operator and the device.

6.5. Relevance for DESIRE6G

This use case is particularly relevant for the point of view of the user interaction in real-time augmented reality environment. This requires ultra-low latency with low jitter especially in the forward chain, from the different cameras, the AR processing, and the headset processing, to assure correct user experience while avoiding cybersickness events. This latency will need to be monitored accurately and will be the result of the latency of many processing stages, network segments and wireless link transmission/propagation delays. The pervasive monitoring component provided by the DESIRE6G infrastructure, combined with suitable data plane programmability network functions deployed and handled by the IML, possibly extended at the drone platform, will be the key enabler of the end-to-end quality of service assurance, enabling fast network reaction and seamless reconfiguration at different scaling level (in-band control, MAS, SMO).

6.6. Mapping to DESIRE6G envisioned architecture

Figure 7 shows how this use case will potentially leverage on the DESIRE6G architecture and components, respectively. The application function chain will be instantiated together with the necessary network components (RAN, core, transport) plus infrastructure components by the DESIRE6G SMO layer.

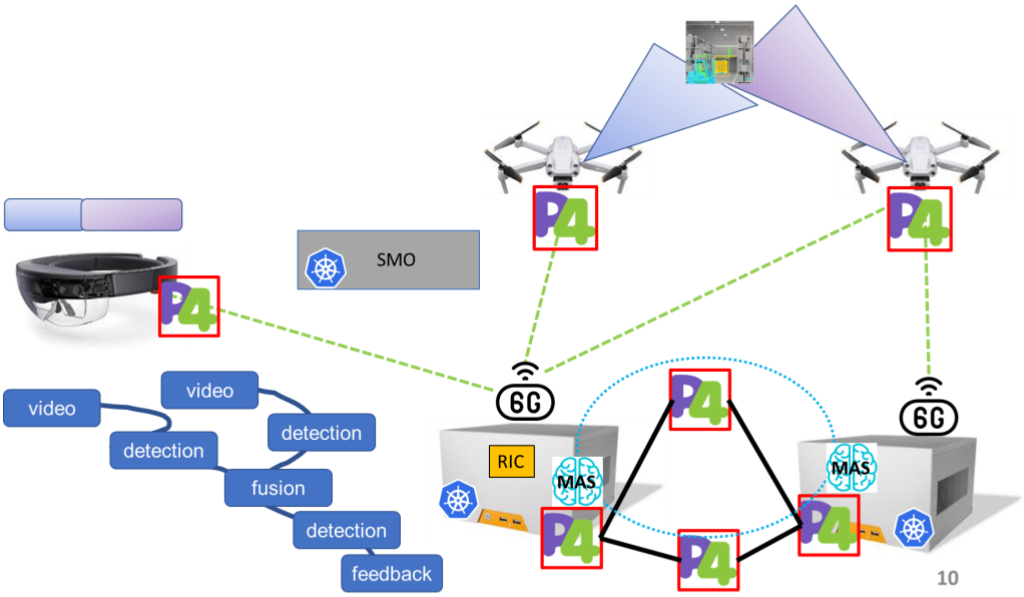


FIGURE 7: AR/VR APPLICATION DEPLOYMENT INSIDE THE DESIRE6G ECOSYSTEM

Then, at steady state, the pervasive telemetry framework (MAS pertaining to the particular app/service and data plane components) will be activated to ensure the perceived zero latency for user experience in the case of soft failures, network events, congestions, handovers, UAV battery issues etc. To this extent, telemetry will be activated either at the terminals, in the radio segment, in the network and in the edge nodes, allowing the collection of significant and heterogeneous metrics, needed as input features for the AI-based operations. In particular, forecasting and detection capabilities running at the MAS will trigger different resiliency-targeted actions, mitigating specific critical conditions with no significant impact on the user experience. Data plane programmability extended also to the User Equipment will enable full real time end-to-end metadata monitoring of the whole app chain performance inside the different networking/IT segments.

7. Digital Twin Use Case

7.1. Description

Digital Twins for robotics are digital replicas of physical assets that create a highly consistent, accurate, and synchronized virtual representation of its physical counterpart, anywhere, anytime and in any conditions (see

Figure 8). This concept has been around for some time now, but it has found limited application mainly because the Digital Twin application has been treated separately from the E2E Digital Twin system. While the Digital Twin application for robotics only refers to the virtual representation of a physical robot that is used for real-time prediction, optimization, monitoring, controlling, and improved decision-making (see

Figure 8), the E2E Digital Twin system, which is being pushed by Industry 5.0, continuously orchestrates, manages, and controls the complete system that includes the physical robot, its virtual replica, but also the available computation and communication infrastructures throughout its entire lifecycle.

Technical description

Applying the robot virtual function concepts to Robot Digital Twins gives the factory operator a unified and modular view of the E2E Digital Twin system and extends the orchestration capabilities beyond the networking aspects. These concepts enhance the flexibility of the robot as well as the infrastructure by allowing to distribute the processing of different application functions that compose the Robotic Digital twin across the Device-Edge-Cloud and try to balance the computing, storage, and networking requirements of the Robotic Digital Twin.

The robots are controlled in real-time remotely by a virtual remote controller or fully autonomous algorithms that reside in the Edge as part of the Digital Twin application. Robot sensor information (e.g., lidar, camera, odometry, joint states) is sent upstream to update the virtual models in real-time, while control instructions about the robot pose will be sent downstream to navigate the robots. The end-to-end control loop latency budget (time delay between data being generated from the sensors and control instruction being correctly received by the actuator) is mostly spent on the processing time of the data received by the sensors; the remaining part of the latency budget limits the communication time to a few milliseconds. The in-network acceleration and optimization, together with the E2E data plane programmability that is offered by DESIRE6G, have the potential to guarantee the strict KPIs of operational digital twins, mainly related to reliability and low latency. In addition, this use case can benefit from the DESIRE6G E2E service orchestration to enable granular use case life-cycle management with minimum resource consumption and maximum energy efficiency.

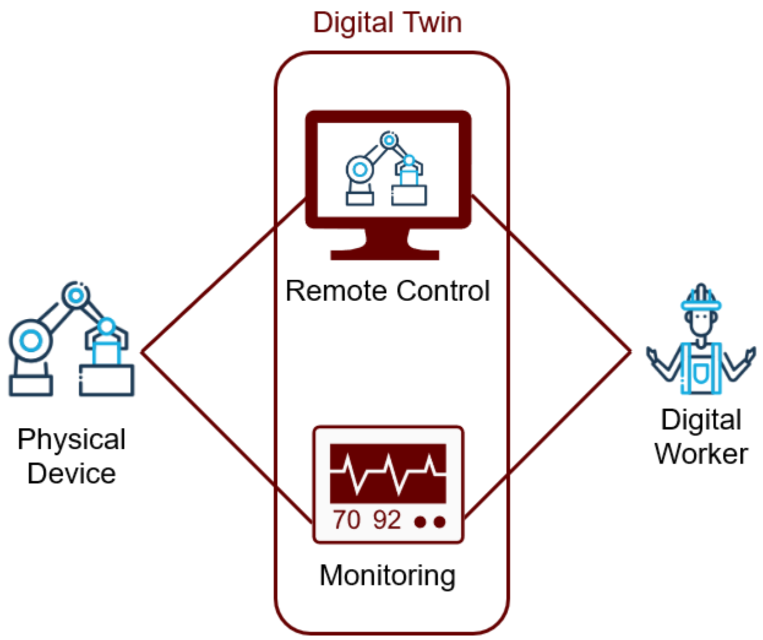


FIGURE 8: BASIC LOGIC BEHIND ROBOT DIGITAL TWIN

7.2. Characterization

7.2.1. Functional Requirements

Table 13 provides the initial list of some key functional requirements that can be already inferred from the use case.

Functional requirement	Description
Support various categories of resources (Cloud/Edge/Device)	The system shall support various categories of computing resources from powerful Cloud servers to resource limited, constrained and heterogenous devices. The diversity of computational needs stems from processing requirements of the computation intensive application functions in the cloud as well as low latency processing requirements in the edge of the network for the application function that needs fast response.
Abstraction and virtualization	The system shall support the abstraction and virtualization of the various categories of resources.
Placement and migration of the use case functions	The system shall support optimized placement and migration of the application and network functions in order to fulfil the strict KPIs and guarantee optimal system level performance.
Mobility	The system shall support simulating the mobility of the robots in the virtual space.
Localization	The system shall support localization of the robots.
Synchronization	The system shall support synchronization across distributed resources, as well as amongst virtualized functions.
Real-time control	The real-time control process needs to calculate control commands (e.g., the new joint velocity value in velocity control) periodically and send them to the actuators. The computations need to fit into a delay budget to satisfy real-time requirements by applying feed-forward control (e.g., PID) that combines the state, timing, and trajectory information.
Timing	The precise timing of control commands is crucial since the actuators of the robot arms expect incoming commands with a given frequency and do not tolerate large timeouts and jitter. The use case needs to ensure the timing requirements of the actuators. In addition, there are less strict timing requirements between the real-time process and the non-real-time one that is needed for the reconfiguration/management of the real-time process.
Time Synchronization	Distributing the Digital Twin application functions in the compute continuum requires for a system that can offer synchronization in time between the distributed compute and network resources for the Digital Twin use case to function properly. If the system does not support time synchronization the application functions of the use case cannot work properly since they depend highly on sharing a common clock.

TABLE 13: DIGITAL TWIN USE CASE FUNCTIONAL REQUIREMENTS

7.2.2. KPIs

Motivated by the advantages of Digital Twins, different standardization bodies and alliances, such as ETSI, 3GPP, 5G Alliance for Connected Industries and Automation (5G ACIA) and Next Generation Mobile Networks Alliance (NGMN), defined new use cases with distinct connectivity requirements that connect people, objects, processes and systems [39] [40] [41] [42].. Table 14 summarizes the key performance indicators (KPIs) to be met for the use case to operate seamlessly. In Digital Twins for robotics these KPIs are very depended on robotic task and the sensors that the robot has. For example, while an autonomously navigated robot with computer vison on the factory floor can require a 100 ms end-to-end latency with reliability of 99.999% and data rate of 1000 Mbps, human-robot interaction with robot manipulator equipped with proximity and distance sensors will require 1 ms end-to-end latency with 1 Mbps data rate.

KPI	Value
End-to-end Latency	1 – 100 ms
Reliability	99.999%
Availability	99.999% to 99,999999%
Data Rate	1-1000 Mbps
Scalability	1-50 nodes
Need for real time data processing	YES

TABLE 14: DIGITAL TWIN USE CASE KPIS

7.3. Technical Components

Table 15 presents the Digital Twin use case technical components that are envisioned for the deployment, management, and operation of the use case.

Category	Technical components
Communication	• Low-latency Radio Access Technologies for connecting the robots (Wi-Fi6, 5G) • Ultra-low latency and extremely reliable wired technologies for static robots that interconnect the Device-Edge-Cloud continuum.
Computation	• Cloud and Edge computing platforms that enable orchestration and management of the Digital Twin virtual functions
Placement	• Orchestration solution that can orchestrate and manage the network and application deployment of the complete end-to-end Digital Twin system.
Monitoring	• Monitoring solution that collects and exposes information not only from the Digital Twin application but also from the network and computing infrastructure.
Devices	• In-network: Switches and routers (SW and HW), Commodity cloud and edge servers (GPU, CPU) • End-devices: robots, cameras, lidars, heterogenous constrained devices (e.g., Raspberry Pis, Jetson Nano)

TABLE 15: DIGITAL TWIN FORESEEN TECHNICAL COMPONENTS

7.3.1. Workloads

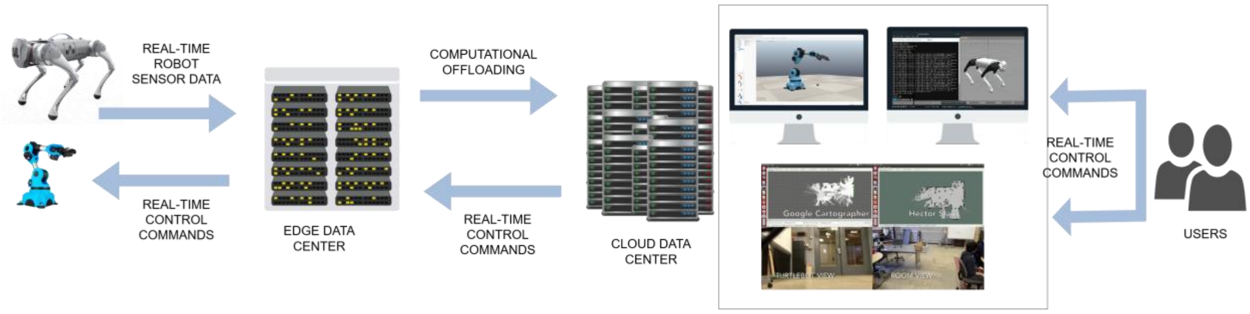


FIGURE 9: DIGITAL TWIN GENERAL CLOSED LOOP ILUSTRATION

Figure 9 illustrates the closed loop between the physical robot and the digital replica. Upstream, the robots expose sensor data such as odometry, lidar, or camera data flows to update the virtual world. Use case specific additional application functions include the robot that can receive low-level control commands (e.g., velocity control, rotation control) and periodically report its internal states (e.g., joint positions, velocity vectors, etc.) to the Digital Twin. Additional real-time and the non-real-time application functions of the Digital Twin application can be the AI algorithms that are considered as analytical models of the Digital Twin and are responsible to describe, understand and predict the future behaviour of the robot.

7.3.2. Infrastructure

To fulfil the above-mentioned strict requirements of the Digital Twin application, its integration with the underlying Computing and Network infrastructures is needed.

Computing infrastructures behind the Digital Twins

Robots are composed of either low-performance and constrained hardware or hardware tailored to a specific task. With the emergence of virtualization, software components of the physical object are represented as modular virtualized functions, whose execution is outsourced to more powerful computing resources. Cloud-based solutions have been initially exploited for implementing such concepts by providing the elastic and powerful computing capabilities required to support the Digital Twin. However, Cloud facilities traditionally reside far away from the robots and while the Cloud providers can ensure certain performance in their infrastructure, very little can be ensured in the network between the robots and the Cloud, especially when multiple Internet providers are involved. As a result, Cloud-based Digital Twins suffer from time-varying network delay, unpredictable jitter, limited bandwidth, or data loss. These drawbacks prevent time-sensitive tasks, including real-time remote control, to be fully supported by the Cloud. To overcome the shortcomings of Cloud computing, Edge computing emerged as a natural extension. Edge computing provides computing capabilities near the physical objects, where the Digital Twin can offload time-sensitive processing from the physical object, which in turn contributes towards further optimization of the hardware costs.

Networking infrastructures behind the Digital Twins

The underlying network infrastructure of the Digital Twin comprises different dynamic and heterogeneous topologies. It can be divided into three segments, (i) Cloud network; (ii) Edge network and (iii) (Radio) Access Network ((R)AN). The Cloud network resides far from the physical objects, relying on switches, routers, and wired connectivity to connect Cloud-based Digital Twins that are suitable for human-scale responsive services and delay-tolerant tasks (e.g., monitoring). The Edge network resides closer to the physical objects, interconnecting multiple (R)ANs and edge computing resources. The Edge network is locally present and exposes radio network information (e.g., radio channel) to Edge-based Digital Twins, namely for time-sensitive tasks (e.g., remote manipulation). Finally, the (R)AN is in the vicinity of the factory floor, providing connection to the physical objects using both wired and wireless connectivity. Different radio access technologies (RATs) are available (e.g., WiFi6, 5G), having different capabilities with respect to latency, range, data rate, power profile, and scalability.

7.3.3. Devices/terminals

On the factory floor, the Digital Twin use case requires interaction with the robots and the customer premises equipment (e.g., 5G CPE or Wi-Fi6 Client) to ensure re-configurability and increased reliability.

7.3.4. Data analytics

Downstream, the Digital Worker interacts with the virtual replica and executes remote control commands to control the robot. This control flow is low-volume simple data, such as position torque or velocity instructions, that usually requires low control cycles when interacting with the robot actuators. Depending on what level from the robotic stack the virtual replica is configured to interact with the robot, the latency can vary from 1 ms values to up to 100 ms. For example, if the remote control is configured to use low-level control that directly interacts with the electoral motor controllers of the robot, the control cycle will be from 10 ms to 1 ms. On the other side, if the remote control is configured to use high-level control that interacts with the motion planning feature of the robot, the control cycle will be from 50 ms to 100 ms. In upstream, while the joint states / odometry data is low-volume data (e.g., simple set points that indicate the position of the joints/wheels/legs) that represents an estimate of a robot's current position and velocity, the camera/lidar data streams are considerably larger amounts of data, which can go up to a few megabytes per second depending on the resolution of the stream. For what concerns the sensor response time for providing measurements, the upstream flows are more latency tolerant supporting latency values from 20 ms to up to 100 ms.

7.4. Other Considerations

7.4.1. Technology gaps

The E2E Digital Twin system creates new business roles and introduces new stakeholders in the value chain. The owner of the computing and/or communication infrastructure (e.g., micro-datacenter and/or 5G network) can be the industrial vertical itself or provided by a third-party infrastructure provider that deploys and manages it for the industrial vertical in the form of a service. In turn, the Robotic Digital Twin application can be provided by a robotics application provider, which delivers its applications through the underlying infrastructure and establishes the connection to the robotic systems.

In traditional Robotic Digital Twin solutions, the Digital Twin application is managed separately with respect to the underlying networking and computing infrastructure. One technological gap comes from the fact that computing platforms and network infrastructures only implement lightweight quality of service approaches that do not support the isolation of important traffic flows among thousands of traffic flows from the factory floor. Another technological gap comes from the closed and proprietary Robotic Digital Twins, networking and computing solutions that prevent the close interaction and adaptability of the main components of the system. The semantic information from the Robotic Digital Twin task, can be used to re-configure and optimize the network and computing infrastructure in order to guarantee optimal performance of the E2E system.

The E2E Data Plane Programmability, Pervasive Monitoring and E2E Orchestration and Management for Digital Twins could potentially solve the above-mentioned technological gaps, but realizing them remains a challenging task. Despite all the expectations, industrial verticals remain sceptical on the maturity of advances in in these fields. There is a lack of research that deals with the integration of these technologies with current network deployments in the context of a Digital Twin system. This is a continuous process in which validation and optimization are crucial to fully deploy Digital Twin systems.

7.4.2. Required datasets

From the use case perspective, the data sources that are available at the factory floor (e.g., lidars, cameras, odometry sensors) can be used to train different types of ML models that improve the performance of the use case or the end-to-end system. Table 16 provides a summary of exemplary ML models for Digital Twins and the required datasets that can be helpful.

	ML model	Required datasets	Outcomes	ML algorithm
Application	Movement prediction	Historic of commands, real-time commands	Predictions on the N Next commands	VAR, TCN, GRU, LSTM
	Task learning	Demonstrations of the task from different knowledge domains (e.g., physical object states)	Generalized task policy	IL, RL
	Risk reduction	Sensor data, video streams, localization data and machinery states	Identification and forecasting unsafe situations	CNN
Infrastructure	Dynamic scaling	Resource usage, date and time, task, number of instances, application KPIs and SLAs	Scale in/out or up/down suggestions	RL, RT, RF, MLP, BN
	Privacy, security and intrusion detection	Infrastructure and network context information, traffic flows patterns, service and infrastructure KPIs	Security breaches and suspicious flows	PCA, K-means, autoencoders
	Heterogeneous RAT selection	Radio network information, available resources, mobility patterns, application KPIs and SLAs	RAT and handover candidate selection	RL, ANN, fuzzy logic

TABLE 16: EXEMPLARY ML MODELS FOR DIGITAL TWINS

7.5. Relevance for DESIRE6G

In order to address the technological gaps described above, providing a DESIRE6G solution for the Digital Twin use case can bring us one step closer to the realization of such use cases in the factory floor. The Digital Twin use case is a latency-sensitive service that needs to guarantee very strict robot KPIs for successful operation. In this kind of mission-critical services where humans are involved, errors in the operation of the service or downtimes are not allowed because any lost or delayed control command may result in a catastrophic event where humans are injured. This use case is a good opportunity for the DESIRE6G platform to show the main benefits through the Service Management and Orchestration layer, the Multi-agent based Network Intelligence and the E2E programable data plane.

7.6. Mapping to DESIRE6G envisioned architecture

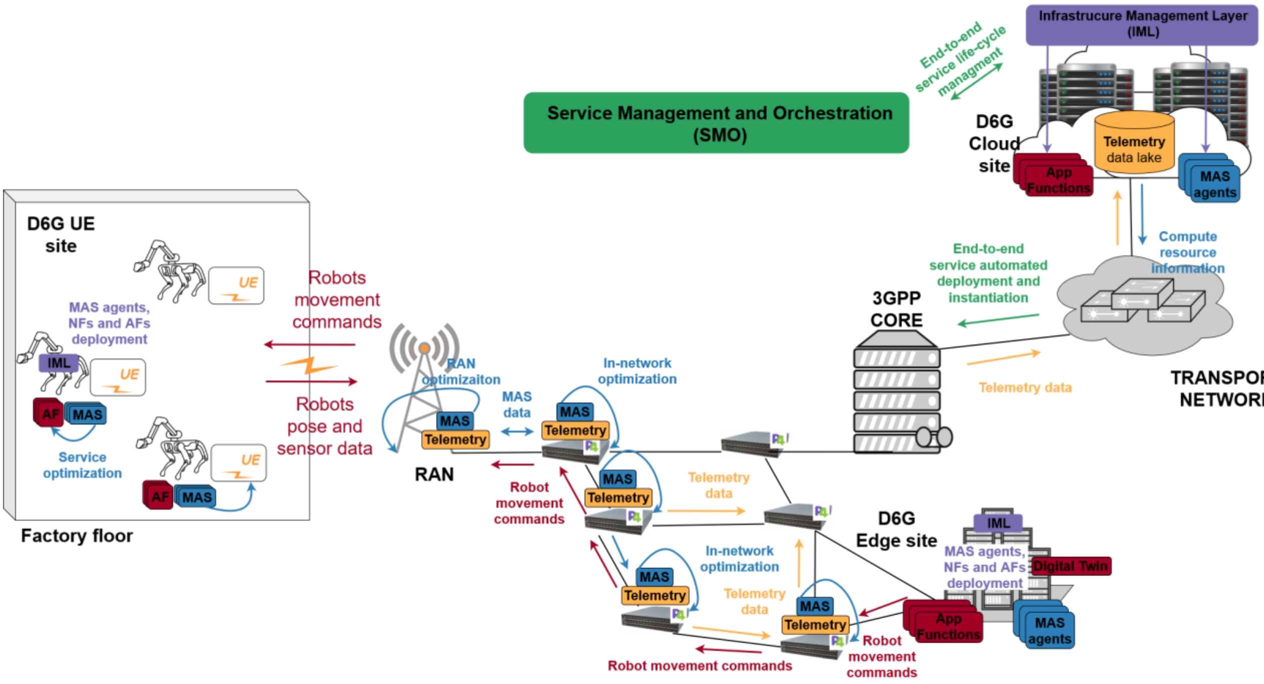


FIGURE 10: MAPPING OF DIGITAL TWIN USE CASE TO DESIRE6G SOLUTION

Figure 10 presents the Digital Twinning use case as enabled by the DESIRE6G solution. While IML, MAS and Telemetry components are fully distributed between the DESIRE6G UE side, Edge site and Cloud site, the SMO is a centralized component with global view of the system.

The SMO oversees the deployment, instantiation, life-cycle management, and in-network optimization of the Digital Twin service. First, it decides in which location the Network Functions (NFs) and the Application Functions (APs) that compose the service should be placed. To do that, the SMO considers the service requirements, the availability of computing resources in the DESIRE6G site, Edge site and Cloud side, and the status of the network. Once the SMO decides the location of the AFs and the NFs, it also selects a set of MAS agents that should be deployed together with the Digital Twin service to fine-tune the network, application or computing infrastructure. The SMO uses the distributed IML to deploy the programable NFs, AFs and MAS agents by deploying the functions in hardware or by proxying the request to the respective VIM.

The Digital Twin continuously consumes the robot pose and other sensor related data in order to update the view of the digital replica. Moreover, the Digital Twin can command the robot to perform desired actions. Any action that is performed on the digital twin is translated into robot movement commands and is executed on the physical robot.

The Digital Twin service can be enhanced with the DESIRE6G multi-agent system that configures and uses the pervasive telemetry system of Desire 6G to receive service specific KPIs (See Table KPIs). The agents use advanced AI algorithms for optimization purposes in the networking domain (e.g., RAN optimiser, transport optimizer) or the Digital Twin application domain. The selected agents that are deployed together with the Digital Twin service share information with each other and in this way, they can solve complex optimization or fault handling problems and help the Digital Twin service to ensure the strict KPIs during its lifetime.

The E2E programmable data plane telemetry in DESIRE6G can be consumed directly by the service-related agents or can be sent to a data lake in the DESIRE6G cloud site, where the SMO can use this data to optimize the performance of the service over a larger time-scale.

8. Intelligent Image Monitoring Use Case

8.1. Description

In modern factories, communication between machines and sensors enables the error-free autonomous operation of the facility. Some sensors may be as simple as thermometers or light sensors, while others can be more complex, requiring far more bandwidth to operate, such as IP cameras, or lidar sensors. Regardless of the amount of data transmitted, each sensor needs to be working ideally for optimal factory operation.

The controller nodes are the ones responsible for collecting this data, making decisions, and sending control commands to the machines present. These computers can be close to the field or may be physically far away, deployed in computer clouds. In contrast to traditional sensor streams, the transmission of video streams at high resolution can significantly burden the communication network, particularly in the case of wireless transmission. Another considerable aspect with bandwidth is billing, cloud providers offer multiple bandwidth plans, and transmitting camera streams indiscriminately would increase the operational cost of the system.

There is a need from the industry for a stable wireless solution for such an environment, where transmission of all the information needed from the sensors and cameras is possible without making the wireless network unstable, slow, and expensive.

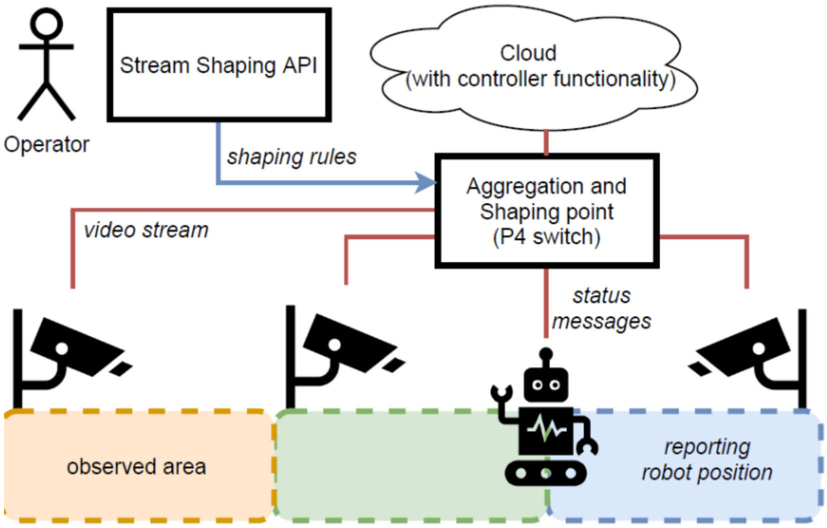


FIGURE 11: IMAGE MONITORING SYSTEM OVERVIEW

The present operational technology (OT) used in discrete manufacturing mainly revolves around large-scale production, offering limited opportunities for tailoring products to specific needs. Most factory networks currently in use rely on wired networks and communication protocols. These networks demand significant investments in terms of both time and finances for their establishment and upkeep. Furthermore, when it comes to reconfiguring production cells, handling the wired connections becomes a laborious and time-consuming process. This task can be made much easier with wireless technologies, which can also greatly speed up reconfiguration and open up new use cases. No wireless technology has yet been able to provide reliability and low latency that are on par with wired connections. With the arrival of 5G and the research going towards 6G, this is changing, and operational technology companies are preparing to use cellular networks to accomplish their Industry~4.0 vision.

While a factory may contain hundreds or even thousands of cameras, production control doesn't require every camera stream continuously for the operation of machines in the manufacturing area (e.g., production cell). Instead, the selection of cameras for controlling the process depends on the specific position and internal conditions of the actuators, sensors, or robots involved.

Instead of modifying the IP cameras, the quality control task may be offloaded to the network. A key benefit of such approach is the plug-and-play support of a wide range of cameras without special capabilities, and it does not require modification at the endpoints. Assuming that the aggregated traffic of both camera streams and the actuators/robots is forwarded through a single aggregation point (e.g., a router/P4-switch connecting to a 5G network) to a remote industrial controller (e.g., running in the edge cloud) as it can be seen on Figure 11.

The quality and thus the data rate of unnecessary camera streams can be reduced at the aggregation point therefore those that are currently not used in the control process do not generate significant data and burden the network. This selection may be based on different factors, such as the current position of the robots, other sensor information (e.g., temperature, movement detection, etc.), or time-based rules. These high-level rules are to be configured by the process managers, who operate the industrial task.

The aggregation point in the network can observe both the state of the industrial setup and the video streams. The network can filter out packets belonging to a selected set of frames (e.g., P-frames in H264 and H265) from the video stream without compromising the connection. This filtering may be dynamically turned on and off based on the abovementioned high-level rules.

8.2. Characterization

8.2.1. Functional Requirements

Table 17 provides the initial list of key technical requirements that can be inferred from the use case. It is important to note that this list of requirements is not exhaustive at this stage.

Functional requirement	Description
Video quality requirement (important stream)	At any given time, if a video stream is marked as important (based on a position or other sensor or status data), the stream needs to be transmitted in perfect quality. This is crucial for the operation of the facility because any delay or quality problem may lead to inaccurate item positions, unfunctional welds, or potential collision of the robots.
Video quality requirement (unused stream)	Unused video streams are not required for decision making; therefore, their quality is insignificant for system operation. The bandwidth that these unnecessary streams use must be kept minimal, to reduce the network load. However, the streams must be kept alive to support a seamless transition to full quality when the unused stream gets marked important again.
Sensor data requirement	The video stream control should not affect the seamless flow of other important sources of data (e.g., temperature sensor).
Delay requirement	The network data needs to be processed without introducing unnecessary delay to the network. Delays may cause inaccurate decision making, resulting in faulty operation.

TABLE 17: INTELLIGENT IMAGE MONITORING USE CASE FUNCTIONAL REQUIREMENTS

8.2.2. KPIs

Table 18 summarizes the key performance indicators (KPIs) to be met for the use case to operate seamlessly.

KPI	Value
Reliability - Sensor data	99% Depending on the reporting frequency of sensors. Fast real-time reaction to changes in the system states requires in-time information for quality control.
Reliability – Camera streams	Depending on the applied video encoding. In H264 and H265, 98-99% when high quality video is needed, but the transmission of I-frames is required for keeping the connection alive.
Availability	99.9999%
Data Rate	10-50Mbps per active camera
Scalability	1-50 IP cameras at an industrial site
Need for real time data processing	YES

TABLE 18: INTELLIGENT IMAGE MONITORING USE CASE KPIS

8.3. Technical Components

Table 19 presents the technical components that are envisioned for the deployment, management, and operation of the latency-sensitive robot control use case.

Category	Technical components
Communication	• Low-latency Radio Access Technologies for connecting the sensors, video streams and robots. ○ Wi-Fi6 ○ 5G
Computation	• Edge computing platforms that enable orchestration and management of the production. • Edge computing infrastructure with hardware accelerators (DPU, SmartNIC or another programmable accelerator)
Placement	• Orchestration solution that can orchestrate and manage the network and application deployment of the complete end-to-end robot control system
Devices	• In the DESIRE6G infrastructure: Commodity edge servers (CPU) with HW accelerator (DPU, smartNIC, FPGA, etc.) • End-devices: Robots, cameras, lidars, sensors

TABLE 19: INTELLIGENT IMAGE MONITORING USE CASE TECHNICAL COMPONENTS

8.3.1. Workloads

Use case specific additional functional modules include a set of IP cameras that can transmit real-time high quality video streams to a control application running at a remote location (edge cloud, cloud). A programmable aggregation point that can filter packets based on the actual importance of the streams. Sensor data streams (robot states and other sensor data) are also sent to the control application through the aggregation point. The importance of a camera stream is determined according to reported sensor data and a set of predefined rules. The non-real-time components include the controller application for the production, that can instruct the aggregation point about the required video streams.

8.3.2. Infrastructure

This use case needs an edge-computing infrastructure with DPU, smartNIC, or other programmable accelerators which can run real-time tasks with satisfying the defined functional requirements. The non-real-time components can run in a virtualized environment (e.g., container, virtual machine) offered by the edge-computing platform.

8.3.3. Devices/terminals

Robotic arms, IP cameras. Various types of sensors, such as temperature, humidity, or vibration sensor.

8.3.4. Data analytics

DESIRE6G systems needs to collect data about the quality of the video streams, the reported sensor states, the robot locations, the load of the aggregation point, the delay caused by propagation and the computation at the edge computing infrastructure may also be needed for evaluating the KPIs of the use case.

8.4. Other Considerations

8.4.1. Technology gaps

Current edge computing platforms and network infrastructures do not support the flexibility of dynamically degrading and improving the quality of the chosen video streams. The deep programmability and various hardware acceleration techniques of DESIRE6G infrastructure could potentially enable the realization of this use case with the defined KPIs.

8.4.2. Required datasets

This use case does not require any data sets.

8.5. Relevance for DESIRE6G

This use case requires low latency and high reliability between the sensors, cameras, and the controller application. The quality control selectively dropping of frames from each stream requires a data plane implementation and needs to be deployed close to the video sources, exploiting the end-to-end programmable data plane of DESIRE6G. The real-time control process of the application could also benefit from the use of hardware accelerators provided by the DESIRE6G infrastructure.

8.6. Mapping to DESIRE6G envisioned architecture

The use case will define different requirements on latency, bandwidth, and loss-tolerance as intents. The DESIRE6G infrastructure will deploy the application and configure the end-to-end path(es) between the machines, sensors and cameras and the edge server(s). The application will run on a DESIRE6G (edge) site where the servers will be equipped with different hardware accelerators that can help in ensuring real-time message processing. The deployment process and the use of hardware accelerators will be supported by IML. In this use case, the industrial site where the IP cameras and sensors are located is also part of the DESIRE6G infrastructure, implementing an UE-side DESIRE6G-site that contains at least one programmable data plane node (the aggregation point) where traffic filtering can be done according to the system's states. This remote site is also managed by a local IML instance that will take care of the deployment of filtering data plane program and its configuration.

9. Latency Sensitive Robot Control Use Case

9.1. Description

High flexibility, in general, is needed to realize cost-effective and customized production by supporting fast reconfiguration of production lines, as well as easy application development. Fast reconfiguration and agile behaviour can be achieved by moving the robot control from the pre-programmed local robot controllers to the cloud. In industrial robotics research, cloud robotics is a major topic and in the last years, several studies [43] [44] [45] have shown the benefits of connecting robots to a centralized processing entity: a) usage of more powerful computing resources in a centralized cloud especially for solving Machine Learning (ML) tasks; b) lower cost per robot as functionalities are moved to a central cloud; c) easy integration of external sensor data and easier collaboration or interaction with other robots and machinery; e) reliability of functions can be improved by running multiple instances as a hot standby in the cloud and the operation can immediately be taken over from faulty primary function without interruption.

Though centralized processing has clear benefits in making the management of industrial processes simple and flexible, cloud-based solutions cannot satisfy the low latency and high reliability network requirements of real-time industrial control (e.g., velocity or torque control of actuators, robot arms, conveyor belts, etc.). Industry 4.0 and 5G propose the use of edge computing infrastructure for this purpose, moving these tasks to the computing nodes located close to the industrial environment. Though the propagation delay can significantly be reduced with this setup, edge-computing nodes still rely on the same virtualization technologies as remote cloud infrastructures. Existing solutions require real-time operating systems to eliminate the effects of CPU scheduling and ensure precise timing (e.g., in velocity control the velocity vectors need to be sent to the robot arms with accurate timing). Newer robot arms have 2 ms or less update time frequency. The real-time control of hundreds of such robot arms requires ultra-fast response times with low jitter that is hard to satisfy with traditional edge computing infrastructure based on non-real-time virtualization solutions (e.g., containers, VMs).

The objectives of this use case includes 1) both the low- (real-time) and high-level (non-real-time) control processes of robot arms are served from the edge cloud, 2) the deployment of real-time control processes on edge-computing infrastructure is capable of satisfying the extreme requirements in terms of ultra-low latency and low jitter, 2) the proposed method can be scaled up with reasonable increase in computational resources and energy consumption, and 3) the real-time control processes are isolated from each other and from the non-real-time tasks.

The high-level workflow is depicted in Figure 12. One or more robot arms are located at an industrial site. The control of such robot arms can generally be split into two components: 1) Low level control process responsible for the calculation of velocity vectors for servo motors requiring precise timing, low latency and low jitter – denoted as real-time control process in the figure, 2) high level control used for, e.g., trajectory computation and AI-based planning that has longer feedback loop thus can be considered as a non-real-time process. The two control blocks have different requirements against the computational infrastructure and the network including both transport infrastructure and the radio channel.

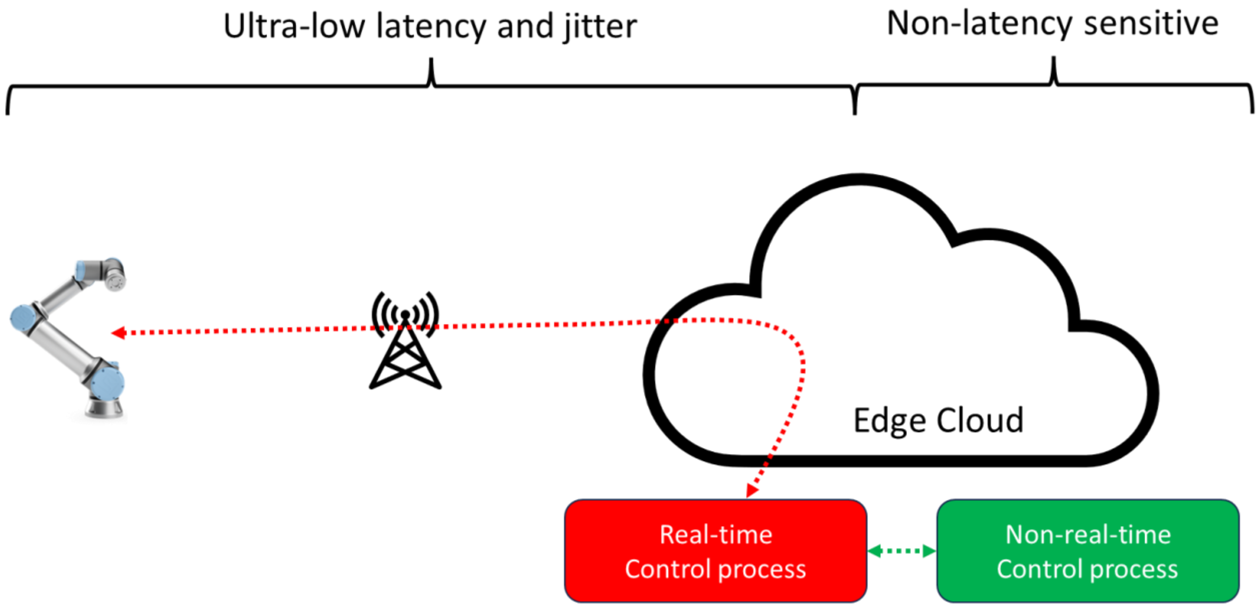


FIGURE 12: REAL TIME AND NON-REAL TIME COMPONENTS RUNNING IN THE EDGE COMPUTING INFRASTRUCTURE

9.2. Characterization

9.2.1. Functional Requirements

Table 20 provides the initial list of key functional technical requirements that can be already inferred from the use case. It is important to note that this list of requirements is not exhaustive at this stage.

Functional requirement	Description
Real-time control requirement (e.g., velocity control requirement)	The smallest building blocks to be controlled are the actuators in this use case. Actuators can be controlled independently. The real-time control process needs to calculate control commands (e.g., the new joint velocity value in velocity control) periodically and send them to the actuators. The computations needs to fit into a delay budget to satisfy real-time requirements.. by applying feed-forward control (e.g., PID) that combines the state, timing, and trajectory information.
Timing requirement	The precise timing of control commands is crucial since the actuators of the robot arms expect incoming commands with a given frequency and do not tolerate large timeouts and jitter. The use case needs to ensure the timing requirements of the actuators. In addition, there are less strict timing requirements between the real-time process and the non-real-time one that is needed for the reconfiguration/management of the real-time process.
Synchronization requirement	Though we assume that actuators can be controlled separately, they are not independent. They belong to a single physical structure with its own kinematics or to a single industrial environment with collaborating actors. Thus, the actuators often need to be coupled in the control process. Synchronization requirements can be defined on different time scales. For example, if a robot stops in a position and then another process is started, but there is no strict time constraint (e.g., a few seconds are acceptable) between the two processes, a remote industrial controller can even solve the synchronization. However, in several cases, this light synchronization is not enough, and thus the low-level control processes also need to work in sync (on a millisecond or sub-millisecond scale).

TABLE 20: LATENCY SENSITIVE ROBOT CONTROL USE CASE FUNCTIONAL REQUIREMENTS

9.2.2. KPIs

Table 21 summarizes the key performance indicators (KPIs) to be met for the use case to operate seamlessly. Note that the required reliability level depends on the robotic task to be implemented. If very accurate movement of robotic arms is needed high reliability is needed with strict delay requirements and no packet loss. If the accuracy is less important (e.g., the robot arm moves between two workbenches) the reliability level is less strict, the loss of 1-2 packets out of 100 will not significantly affect the operation.

KPI	Value
End-to-end Latency	0.5 – 10 ms
Reliability	99.999% - lost and delayed control commands result in uncoordinated behavior
Availability	99.9999%
Data Rate	1Mbps to few Gbps (depending on the number of robot arms to be controlled by a single instance)
Scalability	1-50 robot arms
Need for real time data processing	YES

TABLE 21: LATENCY SENSITIVE ROBOT CONTROL USE CASE KPIS

9.3. Technical Components

Table 22 presents the technical components that are envisioned for the deployment, management, and operation of the latency-sensitive robot control use case.

Category	Technical components

Communication	• Low-latency Radio Access Technologies for connecting the robots.
	  • Wi-Fi6
	  • 5G
	• Ultra-low latency and extremely reliable wired technologies that interconnect the Device to the Edge Computing infrastructure (opt. edge-to-cloud)

Computation	• Edge computing platforms that enable orchestration and management of the robot control components. • Edge computing infrastructure with hardware accelerators (DPU, SmartNIC or another programmable accelerator)
Placement	• Orchestration solution that can orchestrate and manage the network and application deployment of the complete end-to-end robot control system.
Devices	• Commodity edge servers (CPU) with HW accelerator (DPU, smartNIC, FPGA, etc.) • End-devices: robot arm or x86 computer for robot arm emulation

TABLE 22: LATENCY SENSITIVE ROBOT CONTROL USE TECHNICAL COMPONENTS

9.3.1. Workloads

Use case specific additional functional modules include a robot arm that can receive low-level control commands (e.g., velocity control, torch control) and periodically report its internal states (e.g., joint positions, velocity vectors, etc.). The real-time and the non-real-time components of the controller application for, e.g., velocity control are also use case specific, being responsible for communicating with the robot arm to be controlled. These components need to be deployed in the edge computing infrastructure.

9.3.2. Infrastructure

This use case needs an edge-computing infrastructure with x86-based servers with DPU, smartNIC, or other programmable accelerator which can run real-time tasks with satisfying the defined functional requirements. The non-real-time components can run in a virtualized environment (e.g., container, virtual machine) offered by the edge-computing platform.

9.3.3. Devices/terminals

Robot arm with low level control capabilities, server(s) in the edge cloud.

9.3.4. Data analytics

DESIRE6G systems needs to collect data about the end-to-end delay and the jitter. In addition, the delay components caused by propagation and the computation at the edge computing infrastructure may also be needed for evaluating the KPIs of the use case.

9.4. Other Considerations

9.4.1. Technology gaps

Current edge computing platforms and network infrastructures do not support the extreme latency and jitter requirements of this use case. The deep programmability and various hardware acceleration techniques of DESIRE6G infrastructure could potentially enable the realization of this use case with the defined KPIs.

9.4.2. Required datasets

This use case does not require any data sets.

9.5. Relevance for DESIRE6G

This use case requires ultra-low latency with low jitter and high reliability between the robot arms and the controller application. The real-time control process of the application could also benefit from the use of hardware accelerators provided by the DESIRE6G infrastructure.

9.6. Mapping to DESIRE6G envisioned architecture

The use case will define different requirements on latency, jitter, and loss-tolerance as intents. The DESIRE6G infrastructure will deploy the application and configure the end-to-end path(s) between the robot arm(s) and the edge server(s). The application will run on a DESIRE6G (edge) site where the servers will be equipped with different hardware accelerators that can help in ensuring real-time message processing and generation with precise timing. IML will help the seamless deployment of the disaggregated application components to a K8S cluster and a hardware accelerator. The pervasive monitoring component of DESIRE6G can keep track of the experienced end-to-end latency while dedicated MAS agents can trigger the reconfiguration and fine tuning of the system if needed.

10. Cloud Rendered Gaming Use Case

10.1. Description

In addition to AR/VR, HD or holographic video conferencing, and remote presence cloud rendered gaming has also gained significant attention in the past years. In this use case, the user only executes a thin client and the game application itself runs at a remote location (e.g., edge cloud) as depicted in Figure 13. All the commands are sent by the client to the remote application while the game's rendered screen is forwarded as a real-time video stream to the client. This use case requires high throughput (e.g., 4K or 8K video streams) and low latency at the same time. As gigabit-speed access links became widespread, the possibility of temporary and even permanent overloads caused by such novel applications in the access aggregation network (e.g., RAN) has increased.

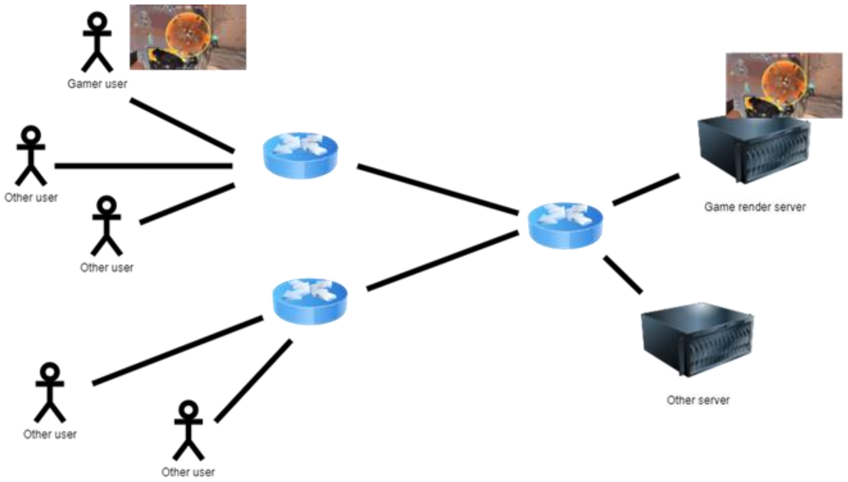


FIGURE 13: CLOUD RENDERED GAMING SCENARIO

These overloaded periods can be handled by over-provisioning the network resources in the access aggregation network, leading to high price: high infrastructure costs and underutilization in most of the time. Overprovisioning in future networks with high-capacity access links is expected to be very expensive and economically not reasonable. As cloud rendered gaming become more popular, the generated traffic may overload the access network, affect and could be affected by other traffic sources. To provide end users with good quality of experience, these applications could adapt their sending rates to network conditions, changing load levels and network congestion. In general, cloud rendered gaming has high throughput demand (e.g., 4K or 8K video stream) on downlink and requires low latency in both uplink and downlink directions.

10.2. Characterization

10.2.1. Functional Requirements

Functional requirement	Description
Real-time video streaming	The cloud rendered game application provides the end user with a real-time video stream at the requested resolution through the thin client. The FPS needs to have a relatively constant value (30, 60, 120 FPS). Less than 20 FPS will perceive a bad gaming experience.
Low latency requirement	Both uplink and downlink communication have low latency requirements to ensure acceptable quality of experience, considering the time between sending a user input and the response animation. A user observing a median latency of over 150 ms with a standard deviation of more than 16.6 ms will perceive a bad gaming experience. The applied transport solution needs to fulfil this requirement.
Performance isolation requirement	The traffic of gamer and other users sharing the network resources needs to be isolated. The resource shares need to be allocated in a fair way (according to predefined policies).

TABLE 23: CLOUD RENDERED GAMING USE CASE FUNCTIONAL REQUIREMENTS

10.2.2. KPIs

KPI	Value
Video quality	Min. 1080p resolution, min. 20 FPS, but FPS is between 30-120 in 99% of the time.
Availability	Less than 100 ms outage in 99% of the time.
End-to-end Latency	20-30 ms for the latency budget of the network Note that RTT less than 150ms results in acceptable gaming experience, but good user experience requires <120 ms.

TABLE 24: CLOUD RENDERED GAMING USE CASE KPIS

KPI	Value
Reliability	99.999% for commands and 98% for the video stream Few percent packet loss can be tolerated in the video stream, but not in the command messages. The minimum fps and latency requirements need to be met during the operation time.
Data Rate	10Mbps to 150 Mbps (per gamer user)
Scalability	1-100 users per session
Need for real time data processing	YES

TABLE 24: CLOUD RENDERED GAMING USE CASE KPIS (CONT.)

10.3. Technical Components

Category	Technical components
Communication	• Low latency and extremely reliable wired and wireless technologies that interconnect the device to the Edge Computing infrastructure (opt. edge-to-cloud) running the cloud rendered gaming application. • Network that ensures performance isolation among users and can handle quality of service policies.
Computation	• Edge computing infrastructure with hardware accelerators (DPU, SmartNIC, or other programmable accelerator) • Edge node with GPU for game rendering
Placement	• Orchestration solution that can orchestrate and manage the network and application deployment of the complete end-to-end gaming stream.
Devices	• Commodity edge servers (CPU) with GPU and other HW accelerators (DPU, smartNIC, FPGA, etc.) that run the gaming application server. • End-devices: x86 computer for running the thin game client

TABLE 25: CLOUD RENDERED GAMING USE CASE TECHNICAL COMPONENTS

10.3.1. Workloads

The thin client will generate continuous command stream to the game application server running in the edge cloud. The game application server sends a high resolution video stream back to the thin client.

Other users are emulated by traffic generators using publicly available traffic models (flow size and arrival distributions).

10.3.2. Infrastructure

This use case needs an edge-computing infrastructure with x86-based servers with GPU running the game application server. Emulating gamer clients and other users requires additional servers. A communication network needs to interconnect the edge-computing infrastructure with the servers emulating end-users. The network infrastructure needs to support quality of service policies including latency requirements and performance isolation.

10.3.3. Devices/terminals

The use case assumes one or more cloud rendering game application server, servers running the thin game client and running traffic generators emulating other users. Other devices to be defined taking part in the implementation of the quality of service policies.

10.3.4. Data analytics

The system needs to collect data about end-to-end delays and throughput shares of different users. In addition, the delay components caused by propagation and the computation at the edge computing infrastructure may also be needed for evaluating the KPIs of the use case.

10.4. Other Considerations

10.4.1. Technology gaps

Current edge computing platforms and network infrastructures only implement lightweight quality of service approaches and do not support the performance isolation among thousands of end users. The deep programmability and various hardware acceleration techniques could potentially enable the realization of non-traditional quality of service approaches and thus this use case with the defined KPIs.

10.4.2. Required datasets

This use case does not require any data sets.

10.5. Relevance for DESIRE6G

This use case requires low latency and high throughput at the same time. The round-trip latency is not ultra-low, but the large jitter cannot be guaranteed. At scale, the requirements can only be guaranteed if performance isolation among different users, slices and QoS enforcement are applied in the network that can eliminate or minimize the effect of other users' traffic on the gaming data flows. This use case can demonstrate the QoS and slicing solutions of DESIRE6G.

10.6. Mapping to DESIRE6G envisioned architecture

The use case will define different requirements on latency and resource sharing as high-level intents. The DESIRE6G infrastructure will deploy the game application server and configure the end-to-end path(s) between the thin game clients and the edge server(s). The game application will run on a DESIRE6G (edge) site where the servers will be equipped with GPU and other hardware accelerators. The site-specific deployment will be done by the IML. The DESIRE6G infrastructure will translate the high-level quality of service intents to QoS policies to be applied by the packet forwarding data plane – including the insurance of low latency and performance isolation implemented by the traffic management solution of DESIRE6G. The pervasive monitoring component of DESIRE6G will keep track of the experienced end-to-end latency and throughput, and congestion on network links while dedicated MAS agents can trigger the reconfiguration and fine tuning of the system if needed.

11. DESIRE6G System requirements

When designing a network system that must support multiple categories of services, like 6G or its predecessor 5G, its requirements cannot be restricted to a comprehensive and closed list of envisioned services. This is so because such a multiservice system must allow for other similar services to be proposed that may not be yet envisioned at the moment of designing the system. More important than compiling a list of "per-service" requirements, it is to distill the key set of technology enablers that will play a role in achieving those requirements stemming from the initial list of services used to bootstrap the design process, but that cannot be taken as a final limitation on what services the system can get to support.

This has been the approach of 3GPP when defining the Service Requirements for the 5G system in [46]. The service requirements of 5G are structured mainly as the requirements for the 5G basic capabilities and a set of performance requirements. The DESIRE6G project has adopted the same approach for defining the service requirements of the DESIRE6G system.

Section 11.1 compiles the DESIRE6G system performance requirements as a collection of KPIs derived from the use cases, whereas section 11.2 presents the requirements that the services supporting the use cases impose on the DESIRE6G enablers. Additionally, the project assesses its impact on the SDGs in section 0.

Both the DESIRE6G enablers and KPIs considered are those that fall into the areas of work of the project, leaving out some technology aspects that even though they are identified as relevant for a future 6G system (e.g. synchronization, merging of sensing and communications, etc.) are not the focus of the DESIRE6G project.

11.1. DESIRE6G KPIs

Table 26 summarises the KPIs of the selected DESIRE6G reference use cases and sets the target value for each of the different KPIs.

Use Case	E2E latency	Bandwidth (per-flow)	Reliability	Availability	Scalability
AR/VR	5ms for the network <20ms total (ideal) <50 ms total (tolerated)	50-100Mbps (uplink) 130Mbps-960Mbps (downlink)	99%	NA	Number of drones per service: 1/10 Number of users per service: 100
Digital Twin	1 – 100 ms for the network	1-1000 Mbps	99.999%	99.999% to 99,999999%	1-50 nodes
Image Monitoring	2ms - 20ms for the network	10-50Mbps	98-99%	99.9999%	1-50 nodes
Robot Control	0.5 – 10ms for the network	1Mbps to few Gbps	99.999%	99.9999%	1-50 nodes
Cloud Gaming	20-30ms for the network <120ms total	10Mbps to 150 Mbps (per gamer user)	Command: 99.999% Video: 98%	NA	1-100 users per session
DESIRE6G unidimensional maximum target	**0.5 ms**	**Few Gbps**	**99.999%**	**99.999999%**	**Hundreds of endpoints**

TABLE 26: DESIRE6G SYSTEM KPIS

KPIs for the DESIRE6G network system are defined in line with the 3GPP definitions in [46]:

- E2E latency: the time that it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.
- Bandwidth: reflects the bandwidth of the most representative flow of each use case at the application level.
- Reliability: in the context of network layer packet transmissions, percentage value of the packets successfully delivered to a given system entity within the time constraint required by the targeted service out of all the packets transmitted.

- Availability: percentage value of the amount of time the end-to-end communication service is delivered according to a specified QoS, divided by the amount of time the system is expected to deliver the end-to-end service. The end point in ”end-to-end” is the communication service interface. The communication service is considered unavailable if it does not meet the pertinent QoS requirements. For example, the communication service is unavailable if a message is not correctly received within a specified time, which is the sum of maximum allowed end-to-end latency and survival time.
- Scalability: number of UEs per use case instance

Some KPIs in Table 26 are defined as a value range. The most stringent value in the range would imply an improved support of the use case (e.g. higher precision distance in the robot use case for a smaller E2E latency). On the other hand, it must be noted that some KPIs are interdependent between them, in particular reliability and availability KPIs are dependent on the latency KPI (as latency reduces availability and reliability are impacted). That means that not all the most stringent KPI values for a given use case can be achieved at the same time since there is a compromise to be achieved between the different KPIs.

The last row in Table 26 is only intended to summarize the most stringent values for each of the KPIs, but it does not have to be interpreted neither as a commitment nor as need to support all those KPI values in combination for any specific use case.

11.2. DESIRE6G Service requirements

11.2.1. E2E Service Orchestration Requirements

Network slicing

The multi-service behaviour and the distinct characteristics of specific services in terms of bandwidth, latency, security, and other network parameters of the 6G use cases envisioned in the industry require the use of network slicing, both in the data plane and in the orchestration plane.

- *DESIRE6G system must support the orchestration of Network Slices as part of the service deployment.*

Intent Based Management

Intent-based management becomes increasingly important in the context of 6G due to the complexity of managing and orchestrating the diverse requirements of the 6G services and the resources associated with network slicing.

- *DESIRE6G system must support Intent Based Management in order to guarantee a high level of abstraction of the technology domains used E2E to deploy a service and to support the diverse requirements of the different services to be supported.*

Cloud Native approach

6G uses cases will require deploying workloads in diverse infrastructure, with diverse requirements. The heterogeneity of the infrastructure considered by the DESIRE6G system ranging from the cloud and even up to the UE makes it very suitable for the use of a Cloud Native approach when deploying the required workloads in support of 6G services and applications.

- *DESIRE6G system must support the orchestration of Network Functions and Application Functions according to a cloud native paradigm across the cloud-edge-far edge continuum with the Functions being dynamically deployed over heterogeneous HW resources and with the possibility of dynamically migration of the Functions.*

Federation of administrative domains

The support of all the use cases presented may be challenging for just one single operator due to the dimensioning required or due to geographical constraints (e.g., coverage holes). The DESIRE6G system supports the possibility of establishing dynamic federation of administrative domains corresponding to different operators in order to fulfil service requests that cannot be served by just one single operator.

- *DESIRE6G system must support federation of different administrative domains in a scalable and secure manner.*

11.2.2. Autonomous Networking Requirements

The support of xURLLC services required by some of the 6G use cases as well as the expected service dynamicity of 6G systems imply short response times from the orchestration layer that can only be achieved by the use of autonomous networking techniques.

- *DESIRE6G system must support distributed decision-making in order to meet near-real time autonomous network operations.*

DESIRE6G project focus on autonomous networking is by means of the inclusion of the Multi-Agent-based network intelligence System (MAS) as explained in the architecture vision in section 0. A Multi-Agent System consists of a set of individual agents that share knowledge and communicate with each other in order to solve a problem that is beyond the scope of a single agent.

Solving a complex problem collaboratively among a set of agents requires to deploy AI/ML functions in different locations in the network connecting them in an AI/ML pipeline, as well as connecting the agents between them. Since services can be reconfigured over time, the corresponding AI/ML pipelines and inter-agent communications will have to be orchestrated for adapting them to the service deployment status.

- *DESIRE6G system must support the orchestration of AI/ML pipelines.*

The inclusion of AI/ML pipelines and inter-agent communication show a new distributed attack surface.

- *DESIRE6G must support the security of MAS components (i.e. , agents) as individual components, notably against CIA attacks (ie, confidentiality, integrity and availability) attacks.*
- *DESIRE6G must support the establishment of trust between agents which collaborate.*
- *DESIRE6G system must support the securing of the AI/ML pipelines and MAS inter-agent communications.*

11.2.3. Programmable Data Plane Requirements

In order to fulfil the stringent performance requirements of 6G use cases, the DESIRE6G architecture vision incorporates a Programmable Data Plane to account for the flexibility required in terms of customised packet treatment features and selection of the most efficient platform for a given function.

- *DESIRE6G system must include a unified Programmable Data Plane layer, from the RAN to the Core network segments, spanning different heterogeneous HW targets.*

A cloud native approach can be used in order to abstract the functions implementation from the actual target HW infrastructure.

- *DESIRE6G system PDP design must follow a Cloud Native approach as way to abstract the implementation of the functions from the different heterogeneous HW targets.*

The distinct characteristics in terms of bandwidth, latency, security, and other network parameters of the 6G use cases envisioned in the industry require the use of network slicing, both in the data plane and in the orchestration plane. The DESIRE6G data plane slicing support has to enable the multitenant use of the PDP layer and enforce the QoS requirements of the slice.

- *DESIRE6G system PDP must support slicing, multitenancy and QoS enforcement.*

The PDP can be leveraged to not only implement Network Functions but also service functions and in general AI functions (at the application or network level). with varying computation requirements.

- *DESIRE6G system must support the offloading of network/service/AI functions to the appropriate acceleration platform.*

The programmable nature of the PDP will enable a fine-grained and real-time visibility of the network by means of customised telemetry features.

- *DESIRE6G system PDP must enable the integration of customised telemetry features in the architecture.*

11.2.4. AI Integration Requirements

AI models can be used to optimize the performance or the operation of a network system supporting demanding 6G use cases whose support would otherwise pose a technoeconomic challenge in the absence of the application of AI.

- *DESIRE6G system must integrate the use of AI models to optimize the performance or the operation of the system.*

DESIRE6G architecture vision comprises several levels (SMO, MAS, PDP) where AI can play a role depending on the optimization objectives of specific use cases.

- *DESIRE6G system must support native integration of AI models at different levels in its architecture.*

Privacy must be preserved when using AI models.

- *DESIRE6G system use of AI models must preserve data privacy specially when third parties are involved in the AI capabilities.*

Use of AI models must be sustainable regarding the use of computation, communication, and energy resources.

- *DESIRE6G system use of AI models has to be sustainable in terms of the computation, communication and energy resources.*

AI algorithms must include provisions for robustness against heterogeneity (e.g., data sets).

- *DESIRE6G system AI algorithm has to be robust in terms of the dataset heterogeneity.*

11.2.5. Pervasive Monitoring Requirements

To comply with the reaction time of the 6G use cases requirements, the network system needs to have a fined grained visibility of the status of the network infrastructure and the services deployed on top.

- *DESIRE6G system must support a pervasive monitoring system capable of conducting both service monitoring and infrastructure monitoring.*

The infrastructure monitoring must be comprehensive and cover all the present infrastructure domains in the architecture. This includes monitoring at the SW level regarding the correct execution of the SW in terms of security.

- *DESIRE6G pervasive monitoring system must extend all the infrastructure domains present in the architecture, including the SW level in terms of securing its correct execution.*

Depending on the use case, monitoring information from the UE may be useful to provide the required service assurance.

- *DESIRE6G pervasive monitoring system must extend to the UE.*

As mentioned in section 11.2.4, DESIRE6G considers the use of AI models to optimize the performance and operation of the DESIRE6G system. These AI models will be one of the consumers of the monitoring data produced by the pervasive monitoring system.

- *DESIRE6G pervasive monitoring system must be capable of making available the monitoring data to AI/ML data consumers in the architecture.*

Due to the huge amount of data that such a pervasive system can generate, scalability considerations regarding the amount of data exposed to higher aggregation layers of the monitoring system need to be considered.

- *DESIRE6G pervasive monitoring system must be scalable in terms of computing and communication resources.*

In order to account for future evolution of the 6G use cases to be supported, there is a need of being capable of adapting the monitoring system to the specific needs of each use case.

- *DESIRE6G pervasive monitoring system must be customisable.*

12. DESIRE6G KVIs

12.1. 6G IA KVI methodology

The 6G Infrastructure Association has published its white paper “What societal values will 6G address?” [47] describing a methodology that can be used to estimate the value impact of 6G use cases by means of Key Value Indicators.

The 6G IA defines a set of societal Key Values relevant for people and society that may be directly addressed or indirectly impacted by future network technology and must be specifically considered for 6G [47]. These KVs can be linked to the UN SDGs [48]. However, while the SDGs are formulated for states, the KVs defined by the 6G IA are formulated with the ICT industry in mind.

FIGURE 14: UN SUSTAINABLE DEVELOPMENT GOALS

Key Value	Societal added value and relation to UN SDGs
Environmental sustainability	KV related to SDGs #6, 13, 14, 15
Societal sustainability	KV related to SDGs #1, 2, 3, 4, 5, 7, 11, 16
Economical sustainability and innovation	KV related to SDGs #8, 9, 10, 12
Democracy	KV related to SDGs #5, 10, 16, as well as linked to securing "Political equality in a pluralistic, liberal society" and to "Protecting EU democracy from external interference"
Cultural connection	KV related to SDG #10, 11, 16, linked to fostering production and access to cultural products (e.g. art -movies, music, literature-, history, trends/new culture domains, e.g. games)
Knowledge	KV related to SDGs #1, 4, 5, 8, 10, 17 especially referring to access to quality education systems and equal educational opportunities
Privacy and confidentiality	KV related to SDG #16; as privacy is an institutionally protected value related to the claim of individuals or institutions to decide on if, when, how, and to what extent information about them is communicated to others. and at the same time "the appropriate use of data relating an individual to a context"
Simplified life	KV reflecting UN SDGs #3 (primarily), #9, #11
Digital inclusion	KV reflecting partly UN SDG #10, in people being part of the digital world
Personal freedom	KV referring to a positive freedom of an individual to control and impact his/her own life
Personal health and protection from harm	KV related to SDGs #2, 3, 6, 13
Trust	Feeling of confidence, faith and explainability in the way that advanced systems (e.g., AI-driven decision making) may impact humans

TABLE 27: KEY VALUES IN 6G IA METHODOLOGY [47]

A technology is valuable for society if it enables KVs and KVIs are useful because they provide metrics to demonstrate this value [47]. A KVI should be a measurable quantity or requirement that in some form provides an estimate of an affected KV [47]

The 6G IA methodology acknowledges that some KVIs require to have a network with the technology in question already deployed and with established use cases for them to be measurable (e.g. injuries in urban traffic). As such the methodology makes a distinction between the methods to evaluate KVIs depending on the stage of the technology development. This distinction is shown in Table 28

Assessment type	Lower TRLs (early in the technology development)	Higher TRLs (later in the technology development)
Subjective assessment	Trials, experiments, interviews	Questionnaires, interviews, focus groups
Objective assessment	Assessment by subject matter experts	Measurements on deployed networks

TABLE 28: METHODS FOR EVALUATING KVIS [47]

The methodology proposes a KVI analysis based on 4 steps as shown in Figure 15. The methodology starts by identifying problems to solve in a use case or use case area. Then it goes on to identify KVs that are net positively affected by the use case in step 1. In step 2 the KVIs are identified as a measure on how successful it has potential to be, how widespread the usage would be [45]. In step 3, the KV enablers are identified as those factors usually related to fulfilling the technical requirements, ensuring the service coverage, adapting to existing ecosystems, and having an attractive value proposition to the end user [47]. Finally in step 4 it is analysed what KPIs provide useful estimates of related KVIs [47]

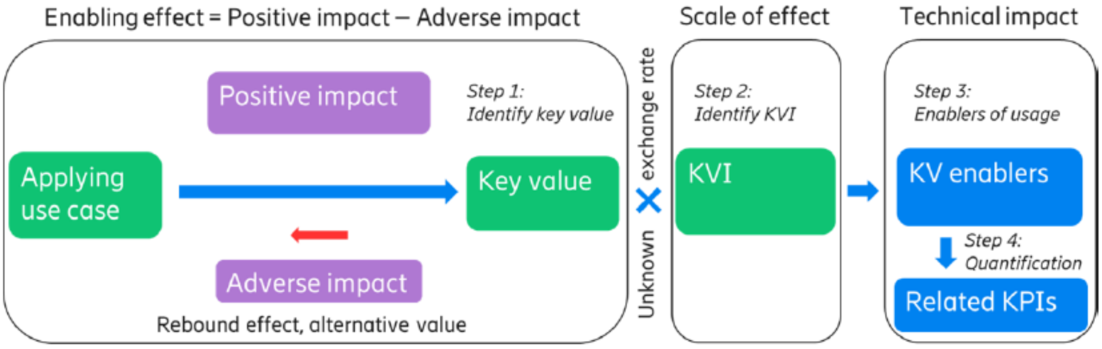


FIGURE 15: KVI ANALYSIS IN 6G IA METHODOLOGY [47]

The 6G IA White Paper [47] then applies the proposed methodology to selected use case areas shown in Table 29 spanning several perspectives: societal (interests of communities), personal (interests of individual users) and business (interests of industries and verticals).

Perspective	Use case area
Societal	1: Emergency response & warning systems
	2: Smart cities with urban mobility
Personal	3: Personal health monitoring & actuation everywhere
	4: Living and working everywhere
Business	5: Assistance from twinned cobots
	6: Sustainable food production

TABLE 29: SELECTED USE CASE AREAS ANALYZED IN 6G IA METHODOLOGY [47]

For each use case area an example of the KVI analysis is conducted identifying KVs, KVIs and KV enablers.

12.2. DESIRE6G KVI analysis

For doing the KVI analysis, the DESIRE6G use cases have been grouped and mapped to different use case areas.

- Emergency response & warning systems area: AR/VR use case
- Industry operations area: DT, Intelligent Image Monitoring, Robot Control use cases
- Living and working everywhere area: Cloud Rendered Gaming

For this grouping of the DESIRE6G use cases, 2 areas are reused from the example analysis in the 6G IA methodology and a new use case area with a business perspective is identified regarding industry operations.

Sections 12.2.1 to 12.2.3 provide the KVs and KVIs identified for the different DESIR6G use cases that will be evaluated by the project. Since DESIRE6G components target TRL-4 at the end of the project, the methods for evaluation of KVIs will be those identified for lower TRLs in Table 28, mainly by assessing how the trials and experiments conducted in the project contribute to the KVI.

12.2.1. Emergency response and warning systems area KVIs

DESIRE6G AR/VR use case can be mapped to the Emergency response & warning systems area. The use of drones and AR/VR headsets for Public Protection and Disaster Relief services can provide an impact on several KVs. Several KVIs identified in the 6G IA methodology are relevant for the AR/VR use case as shown in Table 30

KV affected	Related KVIs
Societal sustainability	Reduced emergency response times due to critical event detection and localization Increased operational efficiency in critical missions
Environmental sustainability	Increased area of protected and surveyed natural habitats and climate preserves
Personal health and protection from harm	Increased operational efficiency in saving lives in remote areas

TABLE 30: DESIRE6G KVIS IN THE EMERGENCY RESPONSE AND WARNING SYSTEMS AREA

12.2.2. Industry operations area KVIs

The Digital Twin, the robot control and the image monitoring use cases have a direct application in the industry vertical segment. In particular, the DT and robot control use cases will promote the use of robots by providing cloudified control or digital twinning capabilities. This increase in the use of robots would enable a reduction of injuries in human workforce by reducing local human involvement in high risk operations. The intelligent image monitoring enables a dynamic reduction in bandwidth consumed by the camera streams that would also have an impact on the adoption of this kind of systems.

KV affected	Related KVIs
Economical sustainability and innovation	Increased use of robots in industrial activities Increased productivity in factory work
Personal health and protection from harm	Reduced injuries in human workforce

TABLE 31: DESIRE6G KVIS IN THE INDUSTRY OPERATIONS AREA

12.2.3. Living and working everywhere area KVIs

Being capable of supporting the Cloud rendered gaming use case will have an impact on the adoption of gaming services by means of a lower investment in expensive dedicated devices for gaming experiences. Once this is achieved several key values are impacted as shown in Table 32

KV affected	Related KVIs
Digital inclusion	Increased footprint of gaming services
Simplified Life	Increased options for in-home entertainment
Cultural connection	Increased number of thematic gaming
Knowledge	Increased rate of learning by gaming

TABLE 32: DESIRE6G KVIS IN THE LIVING AND WORKING EVERYWHERE AREA

13. Conclusions

This deliverable has made a review of the current definition of 6G use cases in the industry. Some use cases have been selected to be used as reference for the work in the project and have already been used to extract the DESIRE6G system KPIs and service requirements to be fulfilled. The impact on SDGs has been assessed in terms of the different dimensions of relevance based on the project objectives and scope.

From this starting point, the project will continue to work on closing the definition of the DESIRE6G architecture that will be included in deliverable D2.2 and that will serve as the root for the technical innovations of the project. In addition to this, the use of AI in the different use cases and the dataset identification work will continue, as well as the realisation of techno economic studies of relevance for assessing the viability of the proposed DESIRE6G system.

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