D2.1 TECHNO-ECONOMIC ANALYSIS OF THE 6G ENVIRONMENT, USE CASE REQUIREMENTS AND KPIS

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Abstract	This deliverable analyzes 6G innovative solutions, focusing on stakeholder interactions and cooperation models. It presents key use cases like disaster response, immersive communication, and digital twin networks. Each use case is described and linked to the UNITY-6G objective, 6G business opportunities and evaluation indicators.
Keywords	Techno-economic analysis, 6G, KPI, KVI, POCs and use cases.

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EXECUTIVE SUMMARY

This deliverable concentrates on a Techno-Economic Analysis (TEA) of Sixth Generation (6G) innovative solutions, highlighting the interactions among key stakeholders, cooperation models, and stakeholder incentives. In this context, we present the UNITY-6G project's identified use cases:

- Use case 1: Sustainable disaster response networks
- Use case 2: Immersive Extended Reality (XR)/holographic communication
- Use Case 3: Digital Twin (DT)-based network evaluation
- Use Case 4: Multi-Radio Access Technology (Multi-RAT) Open Radio Access Network (O-RAN)-enabled Non-Public Network (NPN) for Industry 4.0

In this deliverable, we detail each use case and explain the business opportunities, as well as the key indicators used for evaluation in real-life scenarios. In the first section of this deliverable, we present a TEA of the UNITY-6G project. This analysis includes the identification and definition of critical requirements for 6G from both business and technical perspectives. Additionally, we provide a market analysis and explore the various business opportunities arising from the UNITY-6G use cases.

The deliverable also offers a detailed description of each UNITY-6G use case, outlining the specific requirements, Key Performance Indicators (KPIs), and the measurement methodologies for these KPIs. We establish clear links between each key indicator and the corresponding requirement, the scenarios in the Proofs of Concept (PoCs), and the UNITY-6G objectives. The deliverable concludes with an overview of the UNITY-6G PoCs and scenarios. It further discusses the PoC integration strategies for these use cases, culminating in conclusions and references that synthesize the findings and outline future directions.

Deliverable D2.1 aims to lay a solid foundation for understanding the techno-economic dimensions of 6G networks. It supports the development of tailored KPIs and Key Value Indicators (KVIs) that enable the creation of dynamic, sustainable, and high-performance environments. This analysis will be shared with other Work Packages (WPs) to guide the design, deployment, and management of the PoCs in WP4 and WP6. Furthermore, it details the measurement methodologies for the KPIs, which will serve as a guide for tracking and achieving these indicators throughout the project.

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ABBREVIATIONS

3GPP 3rd Generation Partnership Project

5GC 5th Generation Core

5QI 5G QoS Identifier

6G-IA 6G Smart Networks and Services Industry Association

A1 O-RAN Policy/Model Interface between Non-RT RIC and Near-RT RIC

ACT Actuator (UNITY-6G management entity)

AE Analytics Engine (UNITY-6G management entity)

AF Application Function

AI Artificial Intelligence

AI/DRL Artificial Intelligence / Deep Reinforcement Learning

AI/ML Artificial Intelligence / Machine Learning

AMF Access and Mobility Management Function

AP Access Point

API Application Programming Interface

ARPU Average Revenue Per User

BESS Battery Energy Storage System

CAPEX Capital Expenditures

CAPIF Common API Framework (3GPP)

CNC Centralized Network Controller (TSN)

CNF Containerized Network Function

CQI Channel Quality Indicator

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COTS Commercial Off-The-Shelf

CCA Clear Channel Assessment (Wi-Fi)

CS Cloud Service

CU Centralized Unit (RAN)

dApp Real-Time RAN Application (deployed on DU/CU/AP; project usage)

DE Decision Engine (UNITY-6G management entity)

DLT Distributed Ledger Technology

DMO Domain Management Orchestrator (project-specific)

DT Digital Twin

DU Distributed Unit (RAN)

E2 O-RAN Near-RT Control Interface (Near-RT RIC ↔ RAN)

EDCA Enhanced Distributed Channel Access (Wi-Fi)

E2E End-to-End

EE Energy Efficiency

ES Experimental Scenario

ESG Environmental, Social, and Governance

ETSI European Telecommunications Standards Institute

ETSI MEC ETSI Multi-access Edge Computing

ETSI ZSM ETSI Zero-touch network and Service Management

F1 3GPP CU–DU split interface

GenAI Generative AI

IDMO Intent-Driven Multi-domain Orchestrator (project-specific)

IntaaS Integration as a Service

IRR Internal Rate of Return

ISP Internet Service Provider

KPI Key Performance Indicator

KVI Key Value Indicator

LCM Lifecycle Management

LCOE Levelized Cost of Electricity (Levelized Cost of Energy)

LCOH Levelized Cost of Hydrogen

LEO Low Earth Orbit

LLM Large Language Model

LMF Location Management Function

MANO Management and Orchestration (ETSI NFV)

MCS Modulation and Coding Scheme

MLO Multi-Link Operation (Wi-Fi 7)

ML Machine Learning

MNO Mobile Network Operator

MS Monitoring Service (UNITY-6G management entity)

NAS Non-Access Stratum

NEF Network Exposure Function

NFV Network Function Virtualisation

nGRG O-RAN Next Generation Research Group

Non-RT RIC O-RAN Non-Real-Time RAN Intelligent Controller

NPN Non-Public Network

NPV Net Present Value

NTN Non-Terrestrial Network

O-CU O-RAN Centralized Unit

O-DU O-RAN Distributed Unit

O-RAN Open Radio Access Network

O-RU O-RAN Radio Unit

O1 O-RAN Management Interface (SMO ↔ O-RAN nodes)

O2 O-RAN Orchestration Interface (SMO ↔ Cloud Infra)

OPEX Operating Expenditures

OPC UA OPC Unified Architecture (industrial comms)

OpenCAPIF ETSI implementation of 3GPP CAPIF

OSC O-RAN Software Community

OSPF Open Shortest Path First (routing protocol)

OTIC Open Testing and Integration Center

PCF Policy Control Function

PDR Packet Delivery Ratio

PER Packet Error Rate

PoC Proof of Concept

PRB Physical Resource Block

PMN Private Mobile Network

QoE Quality of Experience

QoS Quality of Service

RAN Radio Access Network

rApp Non-Real-Time RAN Application (O-RAN Non-RT RIC)

RAT Radio Access Technology

RIC RAN Intelligent Controller

ROI Return on Investment

RRC Radio Resource Control

RSRP Reference Signal Received Power

RSRQ Reference Signal Received Quality

RSSI Received Signal Strength Indicator

SA Standalone (5G SA)

SA-AE Semantic-Aware Analytics Engine

SBA Service-Based Architecture

SLA Service Level Agreement

SMF Session Management Function

SME Small and Medium-sized Enterprises

SMO Service Management and Orchestration (O-RAN)

SNO Satellite Network Operator

SNS JU Smart Networks and Services Joint Undertaking

TCO Total Cost of Ownership

TEA Techno-Economic Analysis

TIP Telecom Infra Project

TN Terrestrial Network

TN–NTN Terrestrial–Non-Terrestrial Network Integration

TSN Time-Sensitive Networking

UE User Equipment

UPF User Plane Function

URLLC Ultra-Reliable Low-Latency Communications

VNF Virtual Network Function

VPP Virtual Power Plant

Wi-Fi IEEE 802.11

WP Work Package

W-TSN Wireless Time-Sensitive Networking

xApp Near-Real-Time RAN Application (O-RAN Near-RT RIC)

XAI Explainable Artificial Intelligence

XR Extended Reality

xHaul Unified term for fronthaul/midhaul/backhaul

1 INTRODUCTION

The rapid evolution of wireless communication technologies has paved the way for the development of 6G networks, which promise to significantly improve connectivity by enabling unprecedented levels of performance, flexibility, and sustainability. Deliverable D2.1 provides a technological and economic landscape underpinning the next generation of wireless networks.

This deliverable focuses on the detailed analysis of UNITY-6G's innovative solutions within a 6G context, emphasizing the interactions among key stakeholders, cooperation models, and stakeholder incentives. Building upon 4 use cases: sustainable disaster response networks, immersive XR/holographic communication, DT-based network evaluation, and multi-RAT O-RAN enabled NPN for Industry 4.0; this deliverable aims to refine and expand their technical and market relevance.

Central to this analysis is the identification and definition of critical requirements from both business and technical perspectives, alongside the selection of relevant KPIs and KVIs for the evaluation of the UNITY-6G use cases. These metrics will serve to evaluate the performance, sustainability, and economic viability of 6G solutions, incorporating innovative targets such as energy efficiency, renewable energy utilization, and end-to-end performance across various verticals. Furthermore, the report explores the formulation of SLAs that balance deterministic, stochastic, tail, and average performance guarantees, fostering flexible yet reliable service delivery.

Deliverable D2.1 aims to establish a solid foundation for understanding the techno-economic dimensions of 6G networks, facilitating the development of tailored KPIs and KVIs that support dynamic, sustainable, and high-performance environments. This analysis will be shared with other WPs, guiding the design, deployment, and management of future 6G infrastructures aligned with both technological advancements and market needs.

The remainder of the deliverable is structured as follows:

- Section 2 presents the techno-economic analysis, including: (i) the analysis approach tailored to UNITY-6G; (ii) business opportunities; (iii) the stakeholder landscape (iv) market analysis covering current state and forecasts, growth drivers, key challenges, regional dynamics with a focus on Europe, and strategic implications; and (v) 6G business requirements.
- Section 3 details the use cases. It introduces common KPIs for UNITY-6G and then, for each of the four use cases: (1) Sustainable Networks for Disaster Handling, (2) Real-time XR/Holographic Communication, (3) DT for Integrated 6G Network Evaluation, and (4)

Multi-RAT O-RAN-enabled NPN for time-sensitive Industry 4.0; provides a use-case description, requirements, KPIs, KVIs, and a mapping of requirements to KPIs.

- Section 4 describes the Proofs of Concept and the integration of the UNITY-6G use cases, including integration approach, environments, validation steps, and key outcomes.
- Section 5 summarizes the conclusions, highlighting the main findings, implications, and recommendations.

2 TECHNO-ECONOMIC ANALYSIS

2.1 INTRODUCTION

Initial discussions on 6G architecture emphasize the advanced integration of Artificial Intelligence (AI) into network design, aiming for full automation and intelligent resource management. Standardization efforts, such as those by 3GPP and O-RAN Alliance, are also addressing critical aspects like energy efficiency and enhanced security to meet the growing demands for sustainability and data protection.

6G aims to deliver ubiquitous, resilient, and intelligent adaptive connectivity in highly dynamic environments, where mobility and device density are exponentially increasing. Furthermore, the core network landscape is evolving beyond traditional models dominated by large-scale operators. The rise of Private Mobile Networks (PMNs) requires more flexible, scalable, and adaptable architectures, where classical network functions such as mobility management and charging may become optional depending on specific use cases, such as non-moving industrial devices or public venues. AI plays a central role in this transformation, enabling new functionalities and enhancing communication between users and networks through advanced Large Language Models (LLMs).

The key challenge is to make the core network smarter without increasing complexity; this could be achieved by maintaining existing low-level signalling protocols like Non-Access Stratum (NAS) while leveraging AI for sophisticated tasks such as data processing, feature implementation, and dynamic network management.

Overall, these advancements of technology will make 6G networks more adaptive, efficient, and capable of supporting a wide range of applications from industrial automation to public services driven by AI's ability to optimize and personalize connectivity in real-time. The convergence of these technological innovations makes 6G as an ultra-intelligent communication infrastructure, capable of addressing future challenges while fostering a more connected, secure, and sustainable society.

2.2 TECHNO-ECONOMIC ANALYSIS FOR THE UNITY-6G PROJECT:

In this section, we present some considerations on how the 6G technology considered in the project translates to business opportunities. We do techno-economic and business analysis to understand the potential of 6G unified Open RAN (O-RAN) architectures. But in a first step, it is important to emphasize that these two types of technology analyses differ mainly in scope and focus, inputs and outputs, methodology, level of detail and key use-cases.

The comparison between techno-economic and business analysis is presented in Table 1 Comparison between business Analysis and techno economic analysis.Table 1the following table (Table 1).

Aspect	Business Analysis	Techno-Economic Analysis (TEA)
1. Scope and Focus		
Focus	The organization, market, and business strategy	The technology, engineering performance, and economic viability
Goal	Understand business needs, identify opportunities, and define solutions that deliver value to stakeholders	Quantify how technically and economically feasible a given technology or system is
Key question	Does this make sense for our business goals and market?	Is this technology technically sound and economically competitive?
2. Inputs		
Data used	Market size, demand forecasts, competitor landscape, pricing, regulations.	Technical specs, energy or spectral efficiency, throughput, capital and operational costs.
Focus	Customers, stakeholders, marketing strategy.	Technology performance and cost modelling.
3. Typical Outputs		
	- Business case or business plan - Market requirements - Cost–benefit analysis (at enterprise level) - Process improvement recommendations	- CAPEX & OPEX estimation - Levelized cost (e.g., Levelized Cost of Electricity (LCOE), Levelized Cost of Hydrogen (LCOH), etc.) - Payback period, IRR, NPV - Sensitivity to technical parameters (efficiency, scale, etc.)
4. Methodology		
Methods	- Uses frameworks like SWOT, PESTEL, Porter's 5 Forces, and stakeholder mapping - Focus on *requirements gathering*, *process modelling*, *value chain analysis*	- Combines *engineering models* (e.g., energy balance, throughput) with *economic models* (cash flow, cost scaling) - Often simulation-based or uses process design tools

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Discipline origin	Management, strategy, operations	Engineering, applied economics
5. Level of Detail		
	Macro-level, product, service, or enterprise	Micro-level, system, component, or process
6. Typical Use Cases		
Use cases	- Strategic planning - Product or service design - Process improvement - Organizational change management	- Feasibility of new energy or communication technologies - R&D project evaluation - Infrastructure investment decisions (e.g., renewable energy, telecom, manufacturing)

Table 1 Comparison between business Analysis and techno economic analysis.

In this section, we focus on TEA of the UNITY-6G network architecture, which integrates engineering performance, cost modelling, and policy considerations to evaluate the feasibility and sustainability of disaggregated mobile network architectures. The framework combines quantitative and qualitative assessments across five key dimensions: technical, economic, operational, regulatory, and analytical.

The technical dimension defines the system architecture, network design, and performance indicators that determine both financial and operational requirements. Performance metrics should be evaluated to ensure that Open RAN deployments achieve comparable or superior Quality of Service (QoS) compared to traditional RAN.

Hardware selection, particularly the adoption of commercial off-the-shelf (COTS) servers and white-box radios, directly impacts cost flexibility and vendor independence. The software stack, including open-source and containerized solutions (e.g., Kubernetes, Contained), influences automation potential and scalability. Interoperability and compliance with O-RAN Alliance specifications are essential technical elements, as multi-vendor integration introduces both performance benefits and testing overhead. Energy efficiency, including virtualization-related power consumption, must also be quantified, linking engineering design to total operational cost.

The economic dimension of the analysis quantifies financial viability over the network lifecycle. It considers both capital expenditures (CAPEX), which comprise hardware, software licenses, site deployment, and integration, and operational expenditures (OPEX), such as power consumption, maintenance, orchestration, and personnel costs. Together, these form the Total Cost of Ownership (TCO), which enables a direct comparison between Open-RAN and conventional RAN solutions.

Financial indicators such as Return on Investment (ROI), Net Present Value (NPV), and Internal Rate of Return (IRR) provide insight into profitability and payback periods. The concept of economies of scale is central to Open-RAN economics: as open interfaces standardize hardware and software; multi-vendor competition can significantly reduce component and integration costs. However, supply-chain diversification may introduce new integration costs and interoperability risks, which must be included in sensitivity analyses. Ultimately, the economic dimension assesses whether our UNITY-6G Open RAN solution's cost advantages and long-term savings outweigh the initial integration complexity and uncertainty.

Operational considerations bridge the technical design and real-world implementation. They include deployment scenario characterization, automation potential, and maintenance strategy. Different deployment environments, rural, urban, or private networks, introduce distinct cost drivers, including site density, spectrum cost, and backhaul availability. The introduction of RAN Intelligent Controllers (RICs), both near-real-time and non-real-time, enables AI/ML (Machine Learning) -driven automation, which can reduce OPEX through network optimization and self-configuration.

Software-defined nature of Open RAN allows flexible upgrades and reconfiguration, minimizing vendor lock-in and promoting faster innovation cycles. However, interoperability verification and lifecycle management introduce additional operational effort. Consequently, this dimension evaluates how automation and modularity balance against the increased complexity of multi-vendor operation.

A comprehensive TEA extends beyond cost and performance to include socio-economic and regulatory dimensions. Open RAN compliance with O-RAN Alliance, 3GPP, and ETSI Management and Orchestration (MANO) standards ensure interoperability and market acceptance, while national regulations regarding spectrum licensing, data localization, and security may influence deployment feasibility.

Sustainability considerations such as energy consumption, carbon emissions, and equipment recyclability are increasingly significant in Europe's digital and green transformation agendas. Open-RAN's potential for energy efficiency and lifecycle flexibility aligns with broader environmental objectives.

Moreover, the open ecosystem model can stimulate local innovation and industrial participation, enabling small and medium-sized enterprises (SMEs) to contribute to the telecom supply chain. This supports digital sovereignty and reduces dependency on a limited number of global vendors, aligning economic and strategic policy goals.

The analytical framework integrates technical and economic data into a unified evaluation model. The process begins with defining reference scenarios and estimating traffic demand growth over the analysis horizon. Network topology modelling identifies the number of required sites, radio units, and transport links, followed by quantification of CAPEX and OPEX based on vendor data or empirical benchmarks. Technical performance parameters, obtained through simulation or field trials, are incorporated into cost-benefit models.

Economic indicators, including TCO, ROI, and NPV, are then computed to assess financial outcomes. Sensitivity analysis examines the influence of variables such as energy prices, hardware costs, or user densities, while risk assessment accounts for uncertainties related to interoperability, supply chains, and regulations. The modelling output typically includes comparative results showing Open-RAN versus traditional RAN in terms of TCO reduction, payback time, energy savings, and overall profitability under various demand and cost conditions.

As discussed above, a TEA of the UNITY-6G network architecture combines i) technical evaluation of architecture, performance, and energy efficiency; ii) economic assessment of investment and operational costs; iii) operational analysis of deployment, automation, and maintenance; iv) regulatory and socio-economic assessment of compliance and sustainability; and v) quantitative modelling integrating all dimensions through scenario-based simulation. In this deliverable, we focus on the key elements of this analysis, crucial for the deployment of UNITY-6G solutions in the future 6G networks: **Business Opportunities, Key Players and Stakeholders; Market Analysis and Business requirements**. This approach enables decision-makers to determine whether UNITY-6G offers a technically viable, economically efficient, and strategically sustainable alternative to traditional mobile network architectures.

2.3 BUSINESS OPPORTUNITIES

6G networks will be intelligent systems capable of responding in real-time to emerging demands and changing environments. They will support a wide range of applications and scenarios, such as the Internet of Things, smart grids, autonomous vehicles, intelligent agriculture, and more. The design of telecommunications networks is evolving from a purely communication-focused approach to one that is goal- and intent-oriented.

In the 3GPP standard, one of the initial descriptions of the 6G architecture includes an AI Assistance Interface (AIASI). This interface, defined in the design of the 6G architecture is intended to manage AI functions applied to the management of 6G functions, as illustrated in Figure 2-1.

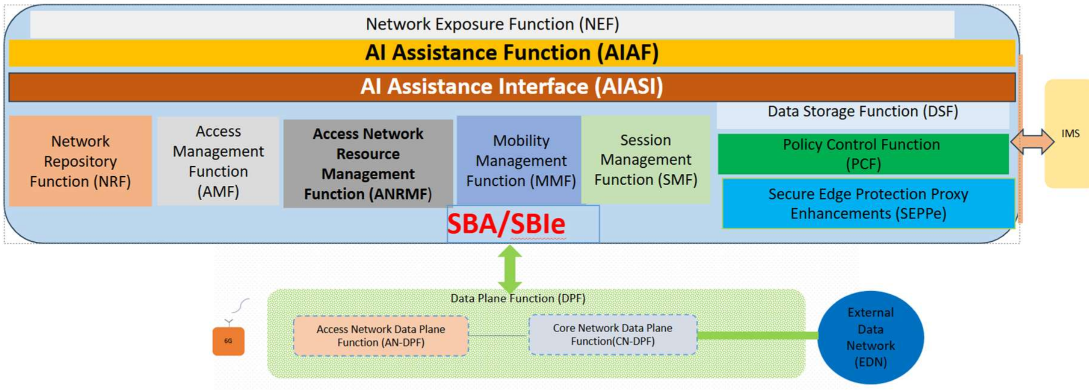

Figure 2-1 Orange 3GPP proposition for the 6G service-based network architecture [1].

6G networks will not only deliver information to meet specific QoS requirements (throughput, latency, reliability), but will also plan, configure, and optimize their functionalities and protocols based on environmental conditions and user demands. In the following, we describe a number of opportunities for 6G networks applications addressed in the following industrial white paper [2]:

- **GenAI on device**: The deployment of Generative AI (GenAI) directly on user devices (smartphones, IoT gadgets, wearables) opens new revenue streams through personalized, real-time AI services. Telecom operators can monetize on-device AI by offering advanced virtual assistants, personalized content generation, and local data processing, reducing dependency on cloud infrastructure. This enhances user experience and enables premium AI-powered features such as real-time translation, image enhancement, and contextual recommendations, while maintaining privacy and reducing latency. Implementing on-device AI involves a comprehensive pipeline that includes data processing, model development, and system integration, as illustrated in Figure 2-2Figure 2-2. This figure provides an overview of the key components and workflow involved in deploying AI models on edge devices, highlighting the interaction between data management, model optimization, and system integration.

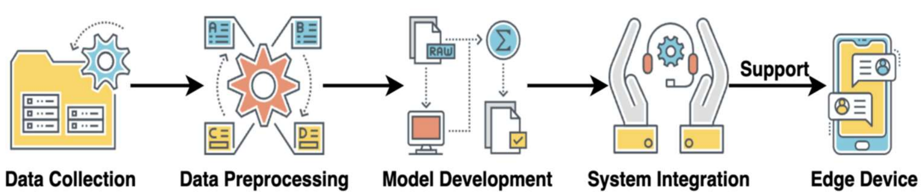

Figure 2-2 Overview of GenAI on device architecture [3].

- **IoT Transportation and robotic communications**: 6G's ultra-reliable, low-latency connectivity combined with AI-driven automation creates vast opportunities in transportation and robotics. Autonomous vehicles, drones, and industrial robots can operate seamlessly with AI-enabled the telecom ecosystem (software developers, vendors, integrators, network operators, etc.), leading to new markets in smart logistics, autonomous delivery, and smart city infrastructure. Telecoms can develop dedicated IoT services, offering secure, high-bandwidth, and low-latency links for fleet management, traffic control, and robotic operations, unlocking revenue from enterprise and government sectors. IoT devices connect to the internet to gather and exchange data, with AI models applied in various ways:
    - **Smart Homes**: Devices such as smart bulbs, thermostats, and security cameras utilize AI models for automation and intelligent decision-making. For example, smart thermostats can automatically adjust temperatures based on user habits, improving energy efficiency, and comfort.
    - **Environmental Monitoring**: IoT sensors monitor environmental data (e.g., temperature, humidity, air quality) in real time. AI models analyse this data to offer suggestions for environmental improvements, supporting sustainability efforts.
    - **Industrial Automation**: In industrial IoT environments, AI models predict equipment failures, optimize production processes, and enhance efficiency while reducing maintenance costs, thereby increasing overall operational reliability.
    - **Smart Agriculture**: By collecting soil and climate data through sensors, AI models help farmers optimize irrigation and fertilization practices to boost crop yields, fostering sustainable agricultural practices.
    - **Healthcare Monitoring**: IoT devices such as wearable health trackers collect vital signs and health data. AI models analyse this information to detect early signs of health issues, enabling timely medical intervention. For example, AI can identify irregular heart rhythms from wearable ECG data.
    - **Traffic Management**: IoT sensors installed on roads and vehicles gather traffic flow data. AI models analyse this data to optimize traffic signals and reduce congestion, improving urban mobility. An example is smart traffic lights that adjust their timing based on real-time traffic conditions.
- **Secure communications**: Enhanced security in 6G networks, powered by AI, will be a key differentiator. Telecom operators can offer secure, AI-driven communication services that detect and mitigate cyber threats in real-time, ensuring data integrity and privacy. This creates new business models around secure enterprise communication, confidential government channels, and critical infrastructure protection. AI-enabled

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security solutions can also provide compliance-as-a-service, helping clients meet regional and international regulations, thus opening new revenue streams.

- **Telecom LLM assistants**: LLM-powered virtual assistants will revolutionize customer engagement and operational efficiency. Telecoms can monetize these AI assistants by offering personalized service onboarding, tailored 6G plans, and proactive customer support. They can also provide automated training for staff and partners, reducing operational costs. These assistants enable seamless, natural language interactions, increasing upsell opportunities, reducing churn, and enhancing customer satisfaction creating new revenue channels through premium AI-driven customer experiences.
- **Semantic communications**: Semantic communications, which focus on transmitting meaning rather than raw data, promises to drastically reduce bandwidth costs and improve robustness. Telecoms can develop new services that leverage semantic encoding for IoT, AR/VR, and mission-critical applications, enabling efficient, high-quality communication even in bandwidth-constrained environments. This opens avenues for innovative applications in healthcare, industrial automation, and smart cities, with monetization potential through premium, low-latency, and reliable semantic services.

2.4 KEY PLAYERS AND STAKEHOLDERS

The Open-RAN paradigm represents a fundamental transformation of the mobile radio access network ecosystem. Its transition from proprietary, vertically integrated solutions toward open, disaggregated, and software-driven architectures has reshaped the roles of traditional actors and attracted new categories of stakeholders. In the context of 6G, these stakeholders jointly define the technical direction, economic sustainability, and policy alignment of next-generation networks. The ecosystem can be broadly categorized into network operators, equipment and software vendors, cloud and IT infrastructure providers, standardization alliances, regulators, industry verticals, research institutions, and testing organizations [4].

2.4.1 Network Operators and Service Providers

Mobile Network Operators (MNOs) remain the central actors in Open-RAN and 6G deployment [8]. They determine the network topology, service models, and business cases that justify investment in open architectures. Leading global operators, such as Vodafone, Telefónica, Orange, Rakuten Mobile, and AT&T, have established dedicated Open-RAN programs and testbeds to evaluate performance parity with legacy RANs.

Their strategic objectives include reducing vendor dependency, enhancing cost efficiency, and accelerating innovation cycles. In the 6G era, operators are expected to leverage Open-RAN to support flexible network slicing, distributed intelligence, and dynamic service provisioning across heterogeneous infrastructures. As the primary customers of the RAN ecosystem, their adoption decisions ultimately dictate market maturity and ecosystem scaling.

2.4.2 Traditional RAN Vendors

The established infrastructure suppliers, Ericsson, Nokia, and Samsung, play a dual role in the Open-RAN transition. On the one hand, they continue to provide most deployed radio access systems; on the other hand, they are progressively aligning their portfolios with open interface standards and virtualized components [5].

Their expertise in radio engineering, large-scale system integration, and global supply-chain operations makes them indispensable in ensuring the reliability and performance of early Open-RAN deployments. For 6G, these vendors are expected to contribute to hybrid architectures that combine open interfaces with advanced functionalities, such as reconfigurable intelligent surfaces, AI-driven beamforming, and joint communication and sensing paradigms. The coexistence of proprietary and open components defines a pragmatic evolutionary path rather than an abrupt replacement.

2.4.3 Cloud-Native and Software-Centric Vendors

A defining feature of Open-RAN is the entry of new, software-driven, and cloud-native vendors. Companies such as Software Radio Systems Ldt. (SRS, the UNITY-6G project partner), Mavenir, Altiostar (now part of Rakuten Symphony), and Parallel Wireless have developed virtualized RAN (vRAN) solutions and RICs based on open interfaces and microservice architectures.

These firms bring the flexibility, automation, and scalability characteristic of the IT industry into telecommunications. Their solutions enable the disaggregation of network functions across cloud and edge platforms, allowing operators to deploy and manage radio resources dynamically. In the 6G context, such cloud-native players are expected to drive innovation in AI-assisted network control, energy-aware orchestration, and the integration of multi-access edge computing.

2.4.4 Cloud and IT Infrastructure Providers

The virtualization of RAN functions has heightened the importance of hardware and cloud infrastructure vendors, including Intel, Dell, Hewlett Packard Enterprise (HPE), and cloud

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hyperscalers. These companies provide the computational substrate, COTS servers, accelerators, and edge-cloud platforms, on which virtualized distributed units (DUs), central units (CUs), and RICs operate [5].

Their participation bridges the gap between telecom and cloud domains, enabling flexible deployment models and elastic scaling. In 6G, where real-time distributed intelligence and massive edge computing will be fundamental, the collaboration between telecom operators and IT/cloud providers becomes a cornerstone of the open ecosystem.

2.4.5 Standardization Bodies and Industry Alliances

The Open-RAN ecosystem is coordinated through several standardization and collaboration bodies [6]. The O-RAN Alliance defines open interface specifications (e.g., F1, A1, E2), reference architectures, and conformance testing procedures that ensure interoperability. Complementary efforts by 3GPP, ETSI, TMForum and regional initiatives such as the Telecom Infra Project (TIP) extend these frameworks toward full-stack integration and pre-commercial validation.

As 6G moves toward more distributed, AI-native architectures, the coordination between these bodies will be critical to harmonize open interfaces, spectrum management, and orchestration layers. Their outputs shape not only technical specifications but also industrial confidence and investment stability.

2.4.6 Governments, Regulators, and Public Funding Programs

Public policy actors, national governments, regulators, and funding bodies have emerged as key enablers of Open-RAN adoption. Through programs such as the EU Smart Networks and Services Joint Undertaking (SNS JU), the U.S. Open RAN Accelerator, and the U.K [4]. Future RAN Competition, policymakers aim to promote vendor diversity, network security, and supply chain resilience.

These initiatives often provide funding for testbeds, pilot deployments, and support for standardization. In the 6G context, Open-RAN aligns with broader policy goals of technological sovereignty, energy efficiency, and green digital transformation. Regulatory frameworks also influence spectrum licensing, cybersecurity compliance, and interoperability certification, all of which affect techno-economic feasibility.

2.4.7 Industrial Verticals and Private Network Operators

Beyond public MNOs, industrial and enterprise stakeholders are increasingly relevant. Manufacturing, logistics, transportation, and energy sectors are adopting private 5G and 6G networks based on Open RAN architectures to meet specific performance and security requirements.

These verticals benefit from modular deployment, lower cost, and greater control over data governance. Their demand for ultra-reliable low-latency communication (URLLC), deterministic networking, and AI-driven automation will accelerate the adoption of flexible Open-RAN solutions. Consequently, the participation of vertical industries expands the addressable market and drives innovation beyond the traditional telecom domain.

2.4.8 Research Institutions and Open-Source Communities

Universities, research institutes, and open-source communities play an essential role in prototyping, validation, and education. Initiatives such as the O-RAN Software Community (OSC), srsRAN Project, and numerous academic testbeds contribute reference implementations, simulation frameworks, and performance analyses that accelerate the industrial uptake of O-RAN.

Academic participation ensures transparency, promotes innovation in AI-native RAN control, and provides early-stage validation for experimental 6G concepts. Moreover, collaborative research bridges theoretical advances with practical deployment guidelines, particularly in areas such as energy optimization, orchestration algorithms, and edge intelligence.

2.4.9 Testing, Integration, and Certification Bodies

Given the multi-vendor nature of Open-RAN, interoperability testing and certification are indispensable. Organizations such as Keysight Technologies, VIAVI Solutions, and Anritsu provide conformance tools, emulators, and validation services to ensure compliance with O-RAN and 3GPP specifications [7].

Integration laboratories and plug-fests organized by the O-RAN Alliance and TIP facilitate ecosystem maturity by identifying interface mismatches and validating performance under realistic conditions. In 6G, where the number of interoperating components is expected to increase substantially, robust testing and certification mechanisms will be crucial for maintaining reliability and security across diverse deployments.

Regarding the readiness of the technology development, the following key stakeholders can be identified around the World: **Europe**, Major operator-led rollouts (Vodafone, Deutsche Telekom, Telefónica, Orange) and large vendor participation (Nokia, Ericsson, Samsung, NEC). Strong public funding and testbeds are accelerating the scaling of Open-RAN. **Asia-Pacific**, Rakuten Mobile (Japan) is a prominent Open-RAN operator and Rakuten

Symphony a software leader; Korea and Japan have strong vendor presence (Samsung, NEC, Fujitsu). China's landscape is more mixed (proprietary vendors dominate). **North America**. Early high-profile Open-RAN attempts (DISH in the U.S.) drove momentum and received government support, but commercial-scale challenges have tempered near-term expansion; active software vendors (Mavenir, Altiostar) remain important.

- **Cloud & IT (Global),** COTS servers, edge platforms and cloud orchestration from Intel, Dell, HPE and hyperscalers are essential enablers for Open-RAN and 6G. (See recent infrastructure collaborations and vendors supporting operator rollouts such as GCP and AWS).
- **Standards / Research (Global)**, O-RAN Alliance, 3GPP, ETSI, TMforum, GSMA, SNS JU and academic/open-source communities provide specifications, testbeds and project funding that underpin Open-RAN, and academic/open-source communities provide specifications and testbeds.

2.5 MARKET ANALYSIS

The emergence of O-RAN is reshaping the global telecommunications landscape and offering a technical and economic foundation for 6G systems. The market for O-RAN solutions, encompassing disaggregated hardware, software, and integration services, is currently in a dynamic growth phase. The O-RAN-based 6G market analysis addresses the following aspects:

1. Current market status and forecast for 6G-era Open RAN (2030s)
2. Growth Drivers for Open RAN in 6G as addressed by UNITY-6G
3. Key Challenges and Headwinds
4. Regional Dynamics, especially in Europe
5. Strategic Implications for Stakeholders

2.5.1 Current market state and forecasts

Industry reports estimated the global Open RAN market at approximately USD 4–5 billion in 2024, with forecasts ranging between USD 19–21 billion by 2030, representing an annual growth rate of over 25% [8]. A neighbouring estimate places the Open RAN market at USD 3.98 billion in 2025, with a projection to reach USD 19.58 billion by 2030 (CAGR ~37.6%) [9]. For the broader RAN market, a forecast indicates that 6G RAN revenues might approach USD 30 billion by 2033 [10]. According to the O-RAN Alliance's Next Generation

Research Group (nGRG) report, Open RAN is being positioned explicitly as a key enabler for 6G use-cases, architectures and ecosystem gaps.

2.5.2 Growth Drivers

The rapid expansion of O-RAN architectures for 6G is driven by the confluence of three forces: the strategic push for network openness and vendor diversification, the technological shift toward cloud-native and AI-driven architectures, and the policy emphasis on supply-chain sovereignty in critical communication infrastructure [8].
In the 5G–6G transition period, O-RAN acts as a bridge between today's virtualized 5G networks and the fully distributed, intelligent 6G systems envisioned for the 2030s. The disaggregation of traditional base station components into open, interoperable modules allows operators to introduce multi-vendor ecosystems and software innovation at a pace not possible with monolithic RAN designs. This modularity is particularly relevant for 6G use-cases, such as large-scale sensing, extreme broadband, non-terrestrial integration, and industrial automation, where flexibility, low latency, and programmability are essential. As such, O-RAN is increasingly seen not merely as a cost-reduction strategy, but as a core architectural paradigm for 6G.

2.5.3 Key Challenges

Despite this momentum, the Open RAN market faces challenges that could shape its trajectory toward 6G. The major one among them is the complexity of system integration in multi-vendor environments, as well as the need for end-to-end performance parity with incumbent single-vendor RAN solutions. Commercial readiness varies significantly by region: while O-RAN trials have matured, large-scale brownfield deployment remains cautious due to interoperability testing requirements, certification gaps, and the economic pressure of flat RAN revenues [11]. Moreover, the 6G roadmap places a strong emphasis on sustainability and energy efficiency, meaning O-RAN solutions will have to demonstrate not only cost-effectiveness but also energy-aware orchestration and lifecycle carbon reduction.

2.5.4 Regional Dynamics, especially in Europe

Regionally, Europe has major operators (Vodafone, Deutsche Telekom, Telefónica, Orange) committing to large-scale O-RAN deployments and aligning with EU-funded research initiatives such as the SNS JU programme and projects like UNITY-6G. This has made advanced Europe in terms of policy alignment and multi-vendor interoperability. Asia-Pacific, led by Japan and South Korea, is a technological frontrunner: Rakuten Mobile and

NTT Docomo have pioneered commercial Open RAN deployments, while vendors such as NEC, Samsung and Fujitsu are exporting solutions globally. North America, though initially propelled by the greenfield deployment of DISH Wireless, has shifted toward selective adoption and test-bed deployments, supported by national initiatives to foster open network ecosystems. Globally, cloud and IT companies, notably Intel, Dell, HPE, AWS, Google Cloud and Microsoft, are emerging as critical enablers by providing the COTS hardware, edge computing and orchestration layers that underpin O-RAN and, by extension, 6G network infrastructures [9].

2.5.5 Strategic Implications

The strategic logic for O-RAN in 6G is compelling. Its open interfaces, AI-native control (via the RIC), and compatibility with edge and non-terrestrial integrations make it the most viable architectural model for flexible, intelligent, and sustainable 6G networks. As private and industrial 5G networks evolve toward non-public 6G deployments, O-RAN is expected to dominate the enterprise segment, where modularity, local control, and cost optimization are paramount. The Open RAN share of the total RAN market, currently below 10 %, is projected to rise substantially as operators plan 6G-era network refresh cycles after 2030.
O-RAN serves as both a market disruptor and a technological precursor to 6G. While short-term adoption remains uneven, the convergence of open interfaces, cloud-native infrastructures and AI-based network intelligence ensures that O-RAN principles will form the backbone of 6G architectures. The market's evolution will therefore be a key determinant of how quickly and equitably 6G can be deployed across regions, industries and use-cases.

2.6 BUSINESS REQUIREMENTS

The shift to 6G mobile networks creates new business requirements that go beyond traditional performance goals. Built on cloud-native, interoperable, and disaggregated architectures, O-RAN signify a structural change in the deployment and revenue generation of mobile networks. The following interconnected domains can be used to summarize the business requirements for O-RAN-based 6G networks: cost effectiveness, vendor diversification, service innovation, interoperability, performance, security, sustainability, and ecosystem collaboration.

2.6.1 Economic Sustainability and Efficiency

Operators must contend with stagnant average revenue per user (ARPU) and rising operating costs because of spectrum densification and energy costs. By utilizing COTS hardware and cloud-based network operations, O-RAN allows for a variable cost model. Modular deployments lower CAPEX by allowing for selected hardware upgrades. Modular deployments permit selective hardware upgrades, reducing CAPEX, while automation and AI-based management lower OPEX. Studies forecast TCO reductions of 30–40 % compared to traditional RANs [12].

2.6.2 Vendor Diversification and Supply-Chain Sovereignty

A multi-vendor ecosystem is made possible by O-RAN's open interfaces, which reduce vendor lock-in. This aligns with the policy goal of supply-chain sovereignty, which is particularly emphasized in North America and Europe, where governments aim to enhance the resilience of digital infrastructure [13]. Software developers and small and SMEs that contribute to the RIC ecosystem are encouraged to innovate by a diverse environment.

2.6.3 Innovation in Services and Cloud-Native Agility

To provide dynamic orchestration, network slicing, and low-latency edge computing, 6G networks will require complete cloud-native integration. For novel services such as DTs, autonomous systems, and extended reality (XR), O-RAN accelerates time-to-market. The RIC creates new service-layer revenue models by introducing an open marketplace for third-party applications (xApps/rApps) [14].

2.6.4 Integration Economics and Interoperability

Achieving multi-vendor interoperability without incurring excessive integration costs is a significant business problem for O-RAN. To reduce deployment friction, standardized interfaces (O1, O2, A1, E2) and certification frameworks are crucial. Scaling multi-vendor networks effectively will depend on the rise of neutral system integrators and "Integration-as-a-Service" (IntaaS) providers [15].

2.6.5 Quality of Experience (QoE) and Performance Parity

O-RAN must match or surpass the performance of current RAN systems to gain commercial acceptability. For industrial and enterprise clients, business models will rely on reliable QoS and Service Level Agreements (SLAs). It is anticipated that AI-based optimization through the RIC will increase energy and spectrum efficiency, helping to achieve parity with proprietary 5G systems [16].

2.6.6 Security, Trust, and Compliance

Zero-trust architectures and transparent software supply chains are necessary because open interfaces and disjointed software expand the attack surface. The adoption of O-RAN in 6G necessitates regulatory compliance, including the EU Cyber Resilience Act and the U.S. FCC's (Federal Communications Commission) Open RAN security recommendations [17]. Therefore, incorporating safe, verified components throughout the ecosystem will be essential to business success.

2.6.7 Green and Sustainable Goals

O-RAN must support circular economy practices and enhance energy efficiency to support global sustainability goals, in accordance with the circular economy guidelines for network equipment outlined in [18]. Modular upgrades and energy-conscious orchestration can significantly reduce the carbon impact of network operations. Funding eligibility and brand repute are becoming more closely associated with ESG (Environmental, Social, and Governance) compliant deployment tactics [19].

2.6.8 Public-Private Funding and Ecosystem Cooperation

Lastly, the O-RAN ecosystem necessitates close coordination between public research projects, industry consortia, and standardization organizations. For co-funding innovation and ensuring interoperability across markets, collaborative activities under the SNS JU, the 6G IA, and international alliances such as the O-RAN Alliance and TIP are essential [20].
In conclusion, O-RAN-based 6G systems must strike a balance between strategic independence and economic optimization. O-RAN offers a route toward sustainable and independent 6G deployment models that strike a balance between cost effectiveness, performance, security, and innovation by fusing open, cloud-native, and intelligent design concepts.

2.7 UNITY-6G USE CASES AND 6G BUSINESS OPPORTUNITIES

Business opportunities related to the use cases defined by UNITY-6G in the following sections are summarized in Table 2.

UNITY-6G use cases	6G business opportunities
Use case 1- Sustainable Networks for Disaster Handling	• Deployable networks-on-demand for emergency coverage,

	• Energy-efficient, AI-managed base stations powered by renewables, • Public–private partnerships for resilient infrastructure, • Data-driven disaster intelligence services, • ESG-aligned financing through sustainable network projects.
Use case 2- Real-time XR/holographic communication	• Holographic telepresence for enterprise collaboration, • Industrial XR services for remote maintenance, • Immersive entertainment (concerts, gaming, tourism), • Personalized QoE-based network slicing, • Edge marketplaces for XR applications.
Use case 3- DT for Integrated 6G Network Evaluation	• 6G Network DT-as-a-Service, • 6G O-RAN validation and certification platforms, • AI-driven automation and energy optimization, • Secure simulation for training and resilience.
Use case 4 - Multi-RAT O-RAN enabled NPN for supporting time sensitive applications for Industry 4.0	• Private Network-as-a-Service for smart factories, • TSN–O-RAN integration for deterministic latency, • Edge AI for predictive maintenance, and • Secure, open industrial ecosystems.

Table 2 UNITY-6G use cases related 6g business opportunities.

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2.8 UNITY-6G OBJECTIVES

This section provides an overview of the objectives of UNITY-6G. Table 3 summarizes each objective, including its description, the corresponding KPIs (outlined in Section 3), and the relevant Proof of Concept (PoC) Experimental Scenarios (ESs), presented in Section 4.

	Description	Related KPIs	Related ESs
Obj#1	Design a new sustainable and scalable integrated AI-native service-based network architecture to support 6G extreme use cases and their requirements in edge-cloud continuum	#17, #19, #24, #26	PoC#1-ES#1, PoC#1-ES#2, PoC#1-ES#3, PoC#2-ES#1, PoC#2-ES#2
Obj#2	Developing distributed native AI and Distributed Ledger Technology (DLT) solutions for integrated architecture in Edge-Cloud continuum	#21, #33, #34, #35, #4, #5	PoC#1-ES#1, PoC#1-ES#2, PoC#2-ES#2
Obj#3	AI-driven dynamic 6G network and service orchestration with enhanced network exposure capabilities in Edge-Cloud continuum	#18, #36, #37, #38, #40, #31	PoC#1-ES#1, PoC#2-ES#1, PoC#2-ES#2
Obj#4	Design DT application for zero-touch network and service management in real time	#27, #28, #29, #41, #42	PoC#1-ES#3
Obj#5	Developing AI-Enabled Dynamic Routing for Multi-RAT Networks with QoS Management	#20, #2, #3, #8	PoC#1-ES#2, PoC#2-ES#1

Obj#6	AI-driven sustainable network management system	#16, #43, #44	PoC#1-ES#1
Obj#7	Design and Evaluation of support for semantic-aware communication	#22, #23, #45, #7	PoC#1-ES#1, PoC#2-ES#2
Obj#8	Exposure Activities for PoCs Exploitation		
Obj#9	Contribute to International Standards for 6G Networks		

Table 3 UNITY-6G Objectives.

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3 USE CASES OF UNITY-6G

3.1 INTRODUCTION

In the context of UNITY-6G project, a set of use cases are defined, aiming to demonstrate as well as validate the envisioned architecture, technologies, and management framework. These use cases have been selected as representative scenarios of 5G and beyond networks, exhibiting diverse requirements in terms of operational efficiency, service delivery high bandwidth, low latency and ubiquitous connectivity. The selected use cases reflect the goals of the project, as far as sustainability, energy-efficiency, integrated AI architecture, and seamless operation of heterogeneous domains are concerned. Each use case captures a critical challenge in 6G communication networks and provides a realistic environment, capable of assessing both the technical and the techno-economic performance of the proposed solutions.

The first use case is about **Sustainable Networks for Disaster Handling**. The aim of this use case is to address the need for resilient, rapidly deployable, and energy-efficient communication infrastructures when an emergency or crisis scenario takes place and affects essential services. Such scenarios include natural disasters, like earthquakes or wildfires, and large-scale power outages. The relevant experiments deal with a shared resource edge cloud continuum to ensure service continuity and at the same time quality. It also facilitates the use of alternative power sources under a Service-Based Architecture (SBA) and the use of DT technologies for the management of disaster-prone areas.

Another critical field of research that is associated with the next use case **is Immersive Experience with Real-time XR/holographic communications**. As the demand for interactive experience is always growing, advanced services are considered an integral part of 6G networks. Semantic communication and AI are proposed as controllers for such applications, including real-time XR and holographic telepresence. Essentially, resources are going to be allocated in a 3D information transmission scenario, without violating the principles of ultra-low-latency and high-reliability.

The third use case concerns **DT for Integrated 6G Network Evaluation**. The purpose behind this use case is strongly associated with network resilience and robustness through proactive decision-making and avoidance of failures. Its goal is to develop a DT to model, predict, and optimize the performance of the whole integrated network. In this way, real data collection, almost real-time evaluation and proactive adaptation of network operations can be achieved. The DT leverages realistic platforms, such as ns3, in order to support the production networks for ML models.

Lastly, there is also a use case related to **Multi-RAT O-RAN enabled NPN for supporting time sensitive application for Industry 4.0**. This is a more specific use case that focuses on industrial environments where diverse, reliable, and flexible communications are mandatory. The goal is to deliver these applications under real-time control and minimized latency. The multi-RAT networks are composed of 6G cellular and IEEE 802.11 technologies, that are going to be updated to become O-RAN compatible. Under this consideration, AI-driven dynamic routing, traffic management, and orchestration will be explored as dApps/xApps/rApps.

These use cases provide a comprehensive testing ground for the innovations proposed by UNITY-6G and are going to be validated through the corresponding PoCs, demonstrating feasibility, scalability, and viability across various network domains.

3.2 USE CASE #1 - SUSTAINABLE NETWORKS FOR DISASTER HANDLING

3.2.1 Use Case #1 Description

Background

Following a natural disaster (e.g., earthquake, hurricanes, wildfires or flood), conventional communication infrastructure is partially or fully unavailable, causing a significant disruption of essential service and inability of individuals to communicate. Emergency response teams need reliable connectivity to coordinate search and rescue operations. UNITY-6G orchestrates rapid deployment of mobile edge computing units, Non-Terrestrial Network (NTN)-mounted RAN elements, and satellite backhaul. AI-native orchestration ensures the real-time deployment and optimization of services based on terrain, demand, and energy availability as illustrated in Figure 3-1.

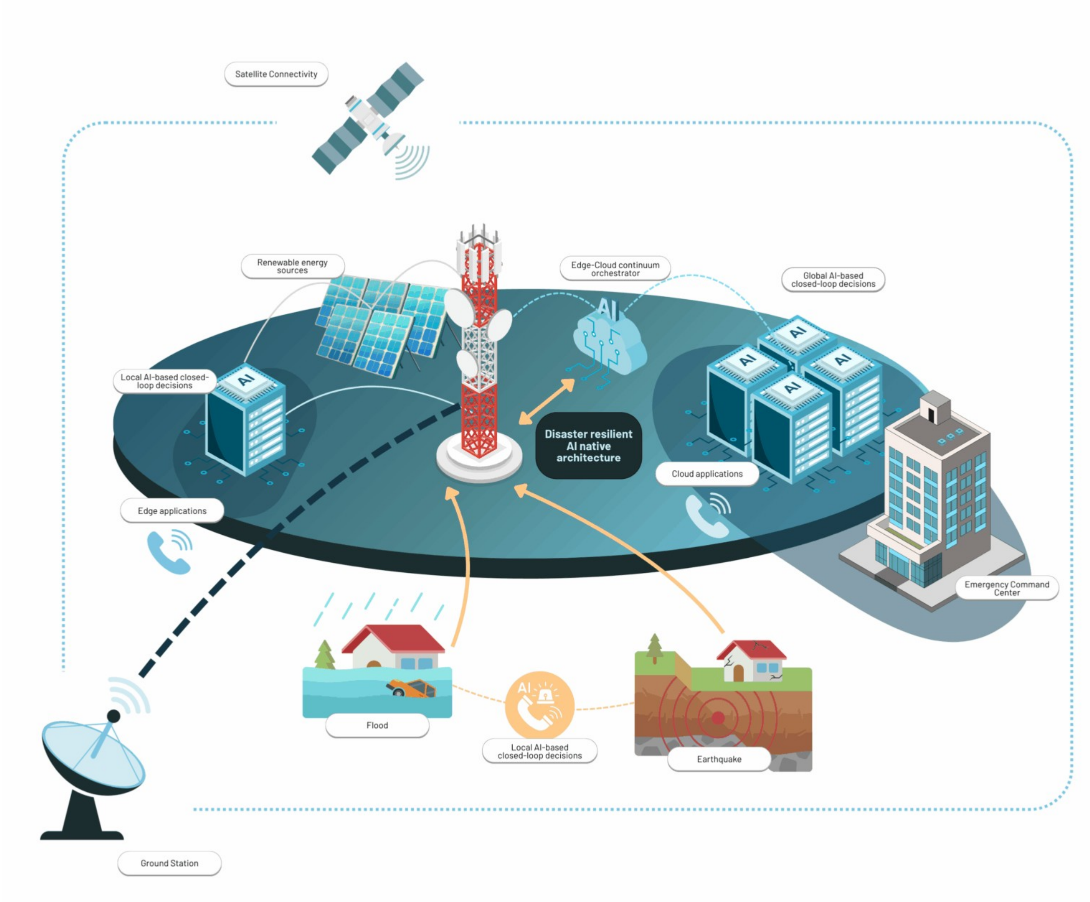

Figure 3-1 Use Case #1

Motivation

The development of a sustainable networks for disaster handling is critical for ensuring the **resilience** of communication infrastructure and the **efficient delivery** of essential services. The challenge is not only to provide robustness and resilience to communication infrastructure but also to provide **sustainable solutions**, reducing the overall cost and environmental impact of network operations by incorporating multiple objectives for network optimization, focusing on multiple aspects: cost, energy type and intents. This use case will **maximize renewable energy utilization** by implementing proactive measures to reduce energy consumption using traffic forecast. This use case will also consider the process **predicting of future disaster event and location** and the process of restoring the network and its services to their pre-disaster state or toa new sustainable state and vice versa.

Disaster handling stages

Designing and maintaining a sustainable network is built from three main lifecycle stages, as shown in Figure 3-2. In the pre-disaster stage, an offline network planning occurs including "what-if" analysis for disaster prediction and recovery plans. In the moment of disaster stage, the network monitoring and prediction algorithms are used to analyse the disaster effects on the network and to enable the maximum potential communication based on the active nodes. The third stage, post-disaster, activated the required algorithms and alarms to enable fast recovery to fully recover network.

Figure 3-2 Sustainable network lifecycle stages

3.2.2 Use case #1 Requirements

For this use case we have specified several system requirements that are linked to KPIs in section 3.2.3. The description, their dependency and relation to KPIs are listed in Figure 3-3.

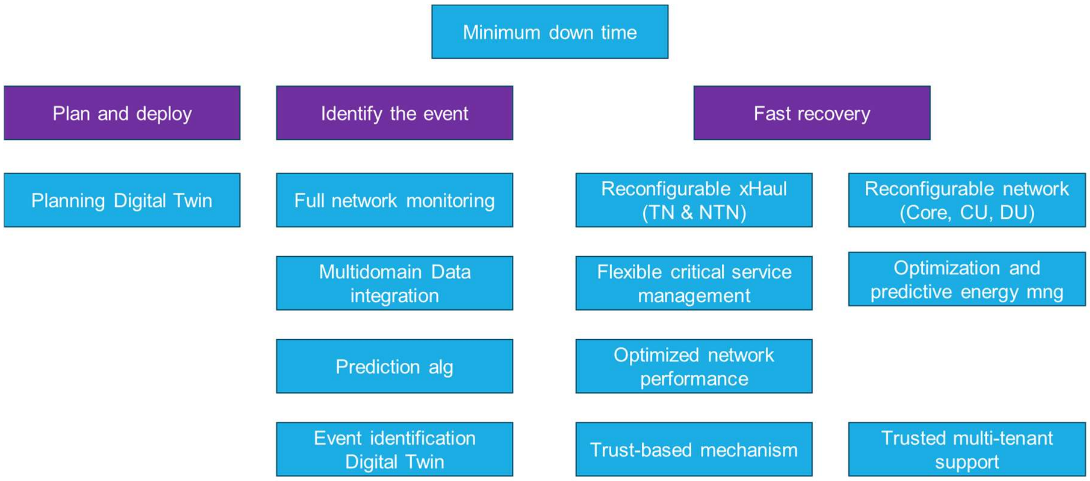

Figure 3-3 Use-case requirements divided by the stages

Pre-disaster

ID	**Req-UC1-01**	**Priority**	**MUST**
Name	Plan and deploy a disaster prepared network		
Description/ Rationale	The network planning must support disaster event and define the actions when a disaster occurs		
Dependency	N/A		
Traceability (Backward)			
Traceability (Forward)	This requirement will be covered in WP3 and demonstrated in PoC#1-ES#1		
UNITY-6G components	• DT + Transport Components • Functional: Monitoring Service (MS) & Analytics Engine (AE)		
Linked KPIs	• KPI#17: Reduce CAPEX and OPEX with shared resources.		

ID	**Req-UC1-02**	**Priority**	**MUST**
Name	Predictive analytics for power outages and network degradation in disaster scenarios		

Description/ Rationale	To proactively avoid service disruption, UNITY-6G must utilize predictive analytics to forecast power outages, infrastructure failures, and network degradation. These insights should guide early mitigation actions like resource rerouting or load shifting.
Dependency	Requires real-time telemetry from infrastructure, historical data, and AI/ML models capable of forecasting failures.
Traceability (Forward)	Predictive AI models (ML/ Deep Reinforcement Learning (DRL)-based) Real-time telemetry and monitoring (MS, AE)
UNITY-6G components	• DT + Transport Components • Functional: MS & AE
Linked KPIs	• KPI#14: Increase up to 20% usage of electricity from renewable sources thanks to close cooperation with local microgrid operation. • KPI#43: Increase integrated network energy efficiency by a factor of 5 through distributed AI techniques, semantic communications, renewable energy usage, proactive strategies for resource allocation, energy aware CNF (Containerized Network Function) placement and task offloading, and energy aware scheduling of AI training and inference. • KPI#44: Increase by at least 20% the ratio of green energy consumed by the network through thanks to awareness of spatio-temporal patterns of renewable energy production and close cooperation with smart grid operators.

ID	**Req-UC1-03**	**Priority**	**MUST**
Name	Predictive analysis at pre-disaster stage		
Description/ Rationale	DT technologies must be employed to make predictions about the possible changes that may impact the network when a disaster is occurring		
Dependency	N/A		
Traceability (Forward)	Will be developed in WP3 and demonstrated in PoC#1-ES#1		
UNITY-6G components	• DT + Transport Components • Functional: AE		

Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services.

ID	Req-UC1-04	Priority	SHOULD
Name	CAPIF Core Function Exposure of Service Discovery, Publication, Invoker Management, Logging and Auditing APIs to support network services at moment of event and post-disaster phase stages.		
Description/ Rationale	UNITY-6G should use OpenCAPIF to expose UC1-relevant NEF APIs (Location Retrieval, QoS) to AFs, providing standardized service discovery, publication, invoker and provider management, as well as invocation logging/auditing, so that disaster-handling applications can dynamically discover and securely access the network exposure capabilities required during incidents.		
Dependency	Requires deployment of a CAPIF Core Function / OpenCAPIF Gateway implementing key 3GPP TS 23.222 service APIs (Discover_Service_API, Publish_Service_API, API_Invoker_Management, Logging_API_Invocation_API, Auditing_API, API_Provider_Management_API), registration of UC1 NEF Location and QoS whenever necessary APIs as CAPIF provider services with OpenAPI descriptions, onboarding of UC1 AFs as CAPIF API Invokers, and integration with UNITY SBA/service bus and security mechanisms.		
Traceability (Backward)	Derived from UC1 need for robust, secure and flexible access to exposure APIs by multiple emergency-related AFs without hard-coded endpoints and from the project objective to align with 3GPP CAPIF and OpenCAPIF for network exposure.		
Traceability (Forward)	Enables unified discovery and controlled access to UC1 Location/QoS exposure, supports observability via invocation logs/audits that feed AE/DE and DT, and eases onboarding of new AFs or additional disaster-handling services.		
UNITY-6G components	• NEF location exposure (5G Core (5GC) service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps • UC1 AFs and orchestrator/xApps as API Invokers		

Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services.

Moment of event

ID	Req-UC1-05	Priority	MUST
Name	Fast restoration at the moment of disaster stage AI-native dynamic resource allocation for optimizing network performance		
Description/ Rationale	To maintain service continuity during disasters, UNITY-6G must dynamically allocate compute, storage, and bandwidth resources based on real-time demand. AI-native techniques should be used to predict resource needs, minimize latency, and avoid congestion. To have flexibility in the network, allowing fast reconfigurability to recover the service as fast as possible, offering a minimum viable service where only the critical applications will be operating.		
Dependency	Requires distributed AI components (MS, AE, Decision Engine (DE) and Actuators ACT) and closed-loop orchestration capabilities.		
Traceability (Forward)	Will be developed in WP4 and be demonstrated in PoC#1-ES#1		
UNITY-6G components	• Distributed MS, AE, DE and ACT components • Real-time AI-based traffic/resource analysers • Edge-cloud orchestration with ML models • AI-native Orchestrator (Edge and Central) • MS, AE, DE and ACT • Smart service orchestration bus • O-RAN xApps/rApps for RIC-based traffic steering • Traffic classification module with semantic awareness • Lifecycle and policy manager for SLA-based orchestration		
Linked KPIs	• KPI#15: Save up to 25% of energy costs by reducing CNF energy consumption.		

ID	Req-UC1-06	Priority	MUST

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Name	Support dynamic reestablishment of the network after disaster event
Description/ Rationale	The network must dynamically reconnect the communication paths between the network entities.
Dependency	N/A
Traceability (Forward)	This requirement will be covered in WP3&4 and demonstrated in PoC#1-ES#1
UNITY-6G components	• DT + Transport Components • Functional: AE, DE and ACT
Linked KPIs	• KPI#21: Reduce the performance penalty due to conflicts by 20% by means of DLT, hierarchical algorithms and policy-based conflict resolution schemes

ID	**Req-UC1-07**	**Priority**	**MUST**
Name	Enable partial network activation by supporting distributed AI architecture		
Description/ Rationale	Supporting partial network, the AI-agents must be able to work and cooperate without a centralized management location		
Dependency	N/A		
Traceability (Forward)	This requirement will be covered in WP3&4 and demonstrated in PoC#1-ES #1		
UNITY-6G components	• DT + Transport Components • Functional: MS, AE, DE and ACT		
Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services.		

ID	**Req-UC1-08**	**Priority**	**MUST**
Name	Energy saving and end to end automation of 5G services		
Description/ Rationale	For integration with energy consumption and ability to decrease it, energy intents must be integrated in the business level and apply the necessary solutions		
Dependency	N/A		
Traceability (Forward)	Assurance of SLAs after disaster		

UNITY-6G components	• The contributions will include AI-driven energy optimization and predictive energy management aimed at reducing energy consumption through traffic forecasting. Additionally, the approach will answer the energy intents and requirements of the client in the business level and integrate it in the end-to-end automation of heterogeneous domain services. • Functional: MS, AE, DE and ACT
Linked KPIs	• KPI#15: Save up to 25% of energy costs by reducing CNF energy consumption. • KPI#16: Reduce radio link power consumption up to 30% per link on average across a transport path (X-haul) due to full network coordinated load balancing, improved link utilization and distributed AI algorithms (between components O-RU, O-DU, O-CU links in Open RAN) • KPI#18: Reduction in the deployment time of heterogeneous domain services.

ID	**Req-UC1-09**	**Priority**	**MUST**
Name	Fast Deployment of Emergency Communication Infrastructure		
Description/ Rationale	In disaster situations, connectivity may be lost or severely degraded. UNITY-6G must support fast deployment of communication infrastructure such as satellite-based platforms, satellite backhaul, and mobile network entities (core, RAN elements) in edge and cloud computing sites. This ensures on-demand, energy-efficient service availability even in damaged or unreachable areas.		
Dependency	Requires pre-integrated orchestration support for edge nodes, and NTN-capable access/backhaul.		
Traceability (Forward)	Used in PoC to demonstrate disaster recovery in disconnected or impaired zones.		
UNITY-6G components	• Mobile Edge Cloud Platforms • NTN-based RAN modules • Satellite access/backhaul integration • Edge orchestrator and AI-based monitoring		

	• Functional: MS, AE, DE and ACT
Linked KPIs	• KPI#18: Reduction in deployment time of heterogeneous domain services • KPI#34: Reduce Open RAN real-time control loops time scales below 10 ms and 10x in NTN for real-time 6G.

ID	Req-UC1-10	Priority	MUST
Name	SBA enabling flexible deployment of emergency services		
Description/ Rationale	To support rapid and reliable emergency response, UNITY-6G must implement an SBA that enables dynamic, on-demand deployment of core, RAN, and edge network functions as modular services. This SBA will allow seamless instantiation, scaling, and migration of services such as mobile core functions, AI inference modules, and orchestration logic in response to disaster events. The architecture should support integration across heterogeneous domains (e.g., terrestrial, non-terrestrial, and private networks), while ensuring interoperability, minimal service disruption, and energy-aware operation.		
Dependency	Depends on the availability of distributed MS, AE, DE, ACT entities, cloud-native network functions, and interoperable orchestration APIs.		
Traceability (Forward)	Feeds into PoCs showcasing disaster communication recovery, TN–NTN integration, and energy-aware service lifecycle management.		
UNITY-6G components	• Distributed Management Plane: MS, AE, DE, ACT • Service-Oriented Orchestrator with SBA support • Edge-cloud continuum orchestration framework • AI-native service bus • Open RAN control loop (near-RT RIC, non-RT RIC) • Lifecycle Management (LCM) interfaces and APIs		
Linked KPIs	• KPI#18: Reduce deployment time of heterogeneous domain services • KPI#35: Improve NTN reliability from $1\text{-}10^{-3}$ to $1\text{-}10^{-4}$		

ID	Req-UC1-11	Priority	MUST

Name	AI-driven energy optimization and predictive energy management
Description/ Rationale	Disaster zones often suffer power loss. UNITY-6G must optimize network energy usage via AI-based models, integrating with local microgrids and renewable sources (e.g., solar/wind). Predictive models will guide workload shifts to avoid blackouts.
Dependency	Relies on real-time energy usage telemetry and AI forecasting capabilities.
Traceability (Forward)	Supports proactive microgrid interaction and Virtual Power Plant (VPP) coordination.
UNITY-6G components	• Energy-aware AI models • VPP coordination module • Energy Data API
Linked KPIs	• KPI#14: Increase green energy usage by 20% • KPI#15: Save up to 25% in CNF energy costs • KPI#16: Reduce radio link energy by 30% • KPI#43: Improve energy efficiency factor by 5×

ID	**Req-UC1-12**	**Priority**	**MUST**
Name	Trust-based mechanisms (DLT, smart contracts) for enforcing fair resource distribution		
Description/ Rationale	In shared emergency network environments, UNITY-6G must ensure secure and transparent resource allocation among tenants. Smart contracts and trust scoring must guide conflict-free access to compute, energy, and bandwidth resources.		
Dependency	Depends on DLT-based decision mechanisms and tenant registries.		
Traceability (Forward)	Feeds into resource governance and incentive strategies.		
UNITY-6G components	• Smart Contract Framework • Distributed Ledger Infrastructure • Policy-based arbitration via Conflict Manager		
Linked KPIs	• KPI#17: Reduce CAPEX/OPEX through resource sharing • KPI#21: Reduce performance penalty from conflicts by 20% • KPI#33: Support more tenants via distributed AI & DLT		

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ID	Req-UC1-13	Priority	MUST
Name	DLT-based trust mechanisms for multi-tenant cooperation		
Description/ Rationale	UNITY-6G must foster collaboration between multiple operators and service tenants in disaster zones. DLTs should enforce tamper-proof logging, contract enforcement, and inter-tenant transparency.		
Dependency	Requires federation support and access-controlled DLT infrastructure.		
Traceability (Forward)	Used in PoC to demonstrate secure multi-tenant resource exchange.		
UNITY-6G components	• Blockchain-based DLT system • Smart contract libraries for multi-party agreements • Federated identity and access control		
Linked KPIs	• KPI#21: Reduce performance penalty by 20% • KPI#33: Enable multi-tenant ressource management		

ID	Req-UC1-14	Priority	SHOULD
Name	NEF-Based Core Exposure for Location Retrieval / Monitoring Events to Support Sustainable Networks for Disaster Handling		
Description/ Rationale	NEF Location/Monitoring Event APIs shall support UC1 by exposing User Equipment (UE) and device position/mobility events (e.g., first responders, sensors, affected users) so that disaster-handling applications and orchestration functions can steer connectivity, prioritize resources and adapt routing based on the impacted geographical area while still meeting critical SLA requirements for safety-related services.		
Dependency	Requires a NEF-enabled 5G SA core integrated with Access and Mobility Management Function (AMF), implementation of Location/Monitoring Event APIs in line with 3GPP TS 29.122/29.522, secure exposure through CAPIF/OpenCAPIF, and registration/management of AF callbacks for UC1 disaster-handling application.		
Traceability (Backward)	Derived from UC1 need for location-aware management of emergency traffic and critical users/devices in disaster zones (e.g., prioritizing connectivity and coverage where incidents occur).		

Traceability (Forward)	Enables location-based traffic steering, prioritization of resources to affected areas, mobility-aware reconfiguration of TN/NTN access, and integration of location information into DT and AE/DE logic for UC.
UNITY-6G components	• NEF location exposure (5GC service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps
Linked KPIs	• KPI 18: Reduction in the deployment time of heterogeneous domain services.

ID	**Req-UC1-15**	**Priority**	**SHOULD**
Name	NEF-Based Core Exposure for QoS to Support Semantic-Aware XR/Holographic Services (NEF session with QoS API)		
Description/ Rationale	UNITY-6G should expose QoS status and allow QoS/traffic influence for critical UC1 flows (e.g., public safety, control traffic, key DT feeds) through NEF QoS-related APIs so that AE/DE and orchestration functions can detect degradation and, when authorized, adapt routes, slices or priorities, helping maintain SLA for emergency services under stressed network conditions.		
Dependency	Requires NEF support for QoS monitoring and traffic influence (QoS flow/5QI modification, QoS event subscriptions), integration with PCF/SMF/UPF and related policies defining which AFs may request QoS influence, and secure exposure via CAPIF/OpenCAPIF.		
Traceability (Backward)	Derived from UC1 objective to preserve the performance of mission-critical services during disasters, when congestion, partial outages or rerouting can otherwise break SLAs.		
Traceability (Forward)	Enables closed-loop QoS control and prioritized handling for selected UC1 services and provides QoS telemetry to evaluators/DT to assess resilience under fault and overload scenarios.		
UNITY-6G components	• NEF location exposure (5GC service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps		

	• UC1 AFs and orchestrator/xApps consuming QoS events (where allowed)
Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services.

Post disaster

ID	Req-UC1-16	Priority	MUST
Name	Optimization in post-disaster stage		
Description/ Rationale	Must fully recover the service by minimizing environmental impact and energy consumption by optimizing resource allocation		
Dependency	Depends on Req-UC1-06		
Traceability (Forward)	N/A		
UNITY-6G components	• DT + Transport Components | Functional: AE		
Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services. • KPI#43: Increase integrated network energy efficiency by a factor of 5 through distributed AI techniques, semantic communications, renewable energy usage, proactive strategies for resource allocation, energy aware CNF placement and task offloading, and energy aware scheduling of AI training and inference. • KPI#44: Increase by at least 20% the ratio of green energy consumed by the network through thanks to awareness of spatio-temporal patterns of renewable energy production and close cooperation with smart grid operators. • KPI #34: Reduce Open RAN real-time control loops time scales below 10 ms and 10x in NTN for real-time 6G.		

ID	Req-UC1-17	Priority	MUST
Name	Seamless transition from emergency state to normal operation with minimal downtime		
Description/ Rationale	After the initial emergency response, the network must transition smoothly back to standard operational states, without disrupting ongoing critical		

	services. This includes reconfiguring service priorities, routing policies, and energy management profiles, even communication link (satellite/terrestrial).
Dependency	Depends on state-aware orchestration and service reconfiguration logic.
Traceability (Forward)	• Tied to AI-driven reconfiguration and DT simulation features.
UNITY-6G components	• Service-based Orchestrator • MS and DE • NTN-based RAN modules • Satellite access/backhaul integration
Linked KPIs	• KPI#18: Reduction in the deployment time of heterogeneous domain services. • KPI#21: Reduce the performance penalty due to conflicts by 20% by means of DLT, hierarchical AI algorithm and policy-based conflict resolution schemes. • KPI#33: Support orders of magnitude more tenants with resource management • KPI#35: Improve NTN reliability from $1\text{-}10^{-3}$ to $1\text{-}10^{-4}$

ID	**Req-UC1-18**	**Priority**	**MUST**
Name	AI-assisted Conflict Detection and Resolution		
Description/ Rationale	The Conflict Detection and Resolution module shall detect potential conflicts arising among the dApps/xApps/rApps outputs and resolve them based on AI techniques (e.g., policy-based decision making, hierarchical, etc.)		
Dependency	None		
Traceability (Forward)	• This requirement will be demonstrated in PoC#1-ES#1		
UNITY-6G components	• AI/ML Management Subsystem in the Intelligence Sublayer, Near RT RIC and xApps/dApps		
Linked KPIs	• KPI#21: Reduce the performance penalty due to conflicts by 20% by means of DLT, hierarchical AI algorithm and policy-based conflict resolution schemes		

3.2.3 Use case #1 KPIs

The KPIs associated with this use case are listed in the table below:

KPIs	Description	Scenario for main KPI	Objective	Measurement Methodology
#14	Increase up to 20% usage of electricity from renewable sources thanks to close cooperation with local microgrid operation.	PoC KPI	N/A	**Definition:** This KPI measures how much the network increases its use of green (renewable) energy as a share of total energy consumption by leveraging (i) awareness of spatio-temporal variations in renewable energy production, and (ii) coordination mechanisms with smart grid operators. Energy exchange information flows through the smart grid interface, enabling the network to understand when and how renewable power becomes available. The goal is to develop an algorithm that aligns the energy generated by local renewable sources with the forecasted needs of the network, ensuring that supply and demand are coordinated efficiently. This algorithm should account for both the geographical distribution of the renewable assets and the spatial characteristics of network demand, allowing it to optimize energy usage across different locations. By incorporating predictive ML models, potentially trained on openly accessible energy and demand data, the efficiency of renewable energy utilization can be improved, and resources can be allocated more intelligently from the network's perspective.

				Beyond technical matching, the solution to achieve this KPI also aims to promote the broader adoption of renewable energy and illustrate how coordinated operation between network providers and smart-grid operators can enhance sustainability and operational resilience Green energy is energy supplied from renewable sources (e.g., solar, wind, hydro) either locally (on-site generation, microgrids) or through certified green energy procurement from the smart grid. Ratio of green energy consumed is the fraction of total network energy consumption that is covered by renewable sources. Increase by at least 20% is a UNITY-6G-defined improvement target expressing that the ratio under the integrated energy-aware management framework must be at least 20% higher than a baseline scenario without renewable-aware optimization. Spatio-temporal patterns of renewable production are time- and location-dependent variations in renewable outputs (e.g., solar peaks, wind intermittency, per-site renewable availability) that are predicted or monitored to optimize network behavior. Cooperation with smart grid operators refers to exchange of forecast information, demand-response signals, flexibility requests, or pricing data that helps the network shift consumption toward renewable-rich periods or locations. This KPI reflects the network's ability to shift energy consumption to greener sources

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				through intelligent orchestration and forecasting. **Standards Used**: No existing telecom standard specifying the 20% improvement threshold; this numerical value is therefore a UNITY-6G requirement. **Measurement Methodology:** The KPI is measured by comparing the network's renewable energy consumption ratio under baseline operation versus under the proposed green-energy-aware integrated design. Baseline scenario (no renewable-aware optimization), operate the network without spatio-temporal forecasting, smart-grid coordination or under a rule-based or non-ML approach. Measure: total energy consumption, renewable (green) energy share. Finally, compute the baseline green-energy ratio. For *renewable-aware integrated* operation, activate renewable production forecasts from the DT or ML algorithm, spatio-temporal awareness models, smart grid cooperation (flexibility, demand response, or renewable availability signals), energy-aware orchestration mechanisms (e.g., shifting workloads, activating/deactivating cells, scheduling charging/discharging of Battery Energy Storage System (BESS)). To measure green energy use under integrated operation, record the renewable energy consumed and total energy consumption over identical or controlled operating windows.

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				To compute the improvement, compare the ratio from the integrated system to the baseline, determine whether the increase is ≥ 20%. To validate consistency across multiple time horizons, perform daily, weekly, or location-dependent measurements to ensure reproducibility. A simplified logical flow is: Run baseline Measure renewable share Enable renewable-aware + smart grid integration Run again Measure new renewable share Compare improvement Extract KPI value.
#15	Save up to 25% of energy costs by reducing CNF energy consumption.	PoC KPI	N/A	Definition: This KPI measures the reduction in energy-related operational costs achieved by lowering the energy consumption of CNFs through optimized deployment, operation, and management mechanisms. CNFs are network functions implemented using cloud-native technologies (e.g., containers, microservices, Kubernetes-based orchestration) and deployed across cloud and edge infrastructures to provide networking, control, and service-management capabilities. CNF energy consumption is the electrical energy consumed by CNFs during operation, including CPU, memory, usage, container runtime and orchestration overhead, inter-service communication and data processing and energy consumption is typically measured in kilowatt-hours (kWh).

				Energy costs refer to the monetary cost associated with the energy consumed by CNFs, derived from measured energy usage multiplied by the applicable electricity price or cost model. Save up to 25% of energy costs refers to a UNITY-6G defined quantitative target indicating that optimized CNF operation should reduce energy-related costs by up to 25% compared to a baseline scenario with non-optimized CNF deployment and management. This KPI is satisfied when $\frac{C_{baseline} - C_{optimized}}{C_{baseline}} \geq 0.25$ where C denotes energy cost over an equivalent observation period. This KPI captures the economic impact of energy-efficient cloud-native operation rather than energy efficiency alone. Standards Used: No telecom or cloud standard mandates a specific 25% energy cost reduction. ICT-52 projects have identified a similar target value in 5GPPP but for Virtual Network Functions (VNFs) [21], therefore, this value is a project requirement. Measurement methodology: This KPI is evaluated by comparing CNF energy costs under baseline operation versus optimized, energy-aware operation. For baseline measurement (non-optimized CNFs), deploy CNFs using standard configurations and default orchestration policies, measure total energy consumption/CPU utilization attributable to CNFs over a defined observation period and calculate baseline energy cost using a consistent electricity price model.

				To enable energy-efficient CNF optimization, apply energy-aware mechanisms such as intelligent CNF placement/migration, scaling, dynamic server activation or deactivation, idle-resource shutdown, and workload-aware scheduling and optionally integrate AI-based optimization or DT–assisted forecasting. These mechanisms can also be adapted to respond effectively under disaster scenarios, ensuring continued efficiency and resilience. Optimized operation measurement, measure CNF energy consumption under optimized operation for the same duration and workload conditions and compute the corresponding energy cost. To compute energy cost savings, compare optimized energy costs to baseline energy costs, calculate the percentage reduction. To evaluate KPI achievement, verify whether the energy cost saving reaches up to 25% and repeat measurements under different traffic profiles to ensure consistency. A simplified logical flow is: - Measure baseline CNF energy cost - Apply energy-aware optimization - Measure optimized energy cost - Compare - Extract percentage savings
#16	Reduce radio link power consumption up to 30% per link on average across a	PoC KPI	Obj#6	**Definition:** The KPI is to decrease the average sum of the radio link powers in the network by 30%. **Standards Used:** No standards are used in this KPI. **Measurement methodology**: the link utilization counters from all the links will be

	transport path (X-haul) due to full network coordinated load balancing, improved link utilization and distributed AI algorithms (between components O-RU, O-DU, O-CU links in Open RAN).			collected over 24 hours. Two setups will be compared: Run#1: without load balancing Run#2: with AI load balancing Based on the counter the links power consumption will be calculated and compared between the Runs.
#17	Reduce CAPEX and OPEX with shared resources.	PoC KPI	Obj#1	**Definition:** The purpose of this KPI is to decrease the network cost (in planning) since a network to support disaster event can be very expensive **Standards Used:** No standards. **Measurement methodology**: Compare the network design cost vs reliability between current planning tool and the enhanced suggested planning tool.
#18	Reduction in the deployment time of heterogeneous domain services.	PoC KPI	Obj#3	**Definition:** This measures the improvement in service deployment speed when orchestrating network services across heterogeneous domains, which may span multiple administrative, technological, or geographical boundaries (e.g., terrestrial,

				NTNs, cloud/edge domains, and domain-specific infrastructure). Deployment time is defined as the total elapsed time from the initiation of a service instantiation request to the moment the service becomes fully operational and ready to handle traffic. Heterogeneous domain services refer to composite services whose constituent components are deployed across different technology domains (e.g., vRAN, core functions, edge nodes, and satellite backhaul) and require cross-domain coordination. Reduction is expressed as a percentage decrease in deployment time compared to a defined baseline (e.g., legacy Network Function Virtualisation (NFV) -based orchestration or current 5G multi-domain orchestrators without AI assistance). **Standards Used:** No standard explicitly defines a "deployment time" threshold across heterogeneous domains. **Measurement methodology**: For *baseline measurement*, use a representative multi-domain service (e.g., a slice including cloud-native core, RAN functions, and an app with satellite backhaul). Measure deployment time using traditional orchestrators or non-optimized workflows (manual or semi-automated). For *optimized deployment* measurement, deploy the same service using the UNITY-6G's advanced orchestration framework (e.g., AI-native service-based orchestrator with cross-domain resource abstraction) and

				measure the deployment time from service intent input to confirmation of operational state. For comparison, calculate the percentage reduction and repeat across multiple representative services to ensure robustness. For reporting, report average reduction across service types (e.g., latency-sensitive, bandwidth-intensive, critical control services) and annotate results with domain complexity (number of domains, orchestration layers, etc.).
#21	Reduce the performance penalty due to conflicts by 20% by means of DLT, hierarchical AI algorithm and policy-based conflict resolution schemes	PoC KPI	Obj#2	**Definition**: This KPI quantifies the effectiveness of conflict-mitigation mechanisms in reducing the performance penalty caused by policy conflicts, resource contention, or contradictory control actions across distributed network domains. Performance penalty refers to the degradation in a measurable network performance metric, such as throughput, latency, packet loss, service continuity, or SLA satisfaction, resulting from uncoordinated or conflicting decisions between multiple controllers, agents, or orchestrators (e.g., Intent-Driven Multi-domain Orchestrator (IDMO)- Domain Management Orchestrator (DMO) interactions or intra-domain orchestrators). Conflict refers to conditions where two or more intent requests, policies, control loops, or resource allocation actions attempt to apply incompatible changes, resulting in suboptimal or unstable network behaviour.

				20% reduction indicates that the optimized system (with DLT logging, hierarchical AI conflict prediction, and policy-based resolution schemes) must reduce the quantified performance penalty by at least 20% compared to the baseline system not using these mechanisms. **Standards used**: There is no single existing standard defining "performance penalty due to conflicts" or its measurement. **Measurement methodology**: For baseline test (*without conflict mitigation*), deploy a representative scenario involving multiple interacting control loops (e.g., RAN slicing, TN-NTN resource allocation, edge orchestration), intentionally induce conflicts (e.g., overlapping intents, contradictory policies, concurrent scaling decisions), measure the resulting performance penalty using standardized performance KPIs (latency increase, throughput degradation, SLA violation rate). For Optimized Test (With DLT + Hierarchical AI + Policy-Based Resolution), enable the full conflict mitigation stack, including, DLT-based immutable decision logging (improves traceability and early detection), hierarchical AI conflict prediction/resolution, policy-based harmonization schemes across domains, run the same test scenarios and record the new penalty values. For comparison and reduction calculation, compute the percentage penalty reduction between baseline and optimized conditions, validate over multiple conflict types

				(resource, intent, configuration, timing conflicts) to ensure robustness. For reporting, provide the mean penalty reduction and variance across multiple runs, document which performance metrics were used and their relative contribution to penalty estimation.
#33	Support orders of magnitude more tenants with resource management using distributed AI and DLT.	Theory/Simulation/ Emulation only	Obj#2	**Definition:** This KPI measures the scalability of network resource management systems to support a significantly higher number of tenants, while maintaining acceptable service performance and isolation. "Orders of magnitude more" refers to 10x or greater increases in the number of concurrently managed tenants compared to a baseline orchestration/control system (e.g., a monolithic NFV MANO or centralized setup without AI or DLT). Tenant support is defined not merely by instantiation capacity, but by the system's ability to maintain fair resource allocation, ensure QoS compliance within acceptable thresholds. Resource management using distributed AI and DLT refers to, hierarchical or peer-to-peer AI agents that manage resources adaptively across domains, and DLT-based accountability layers that log, verify, and enforce multi-tenant resource usage and access rules. **Standards used:** There is no single standard that explicitly defines multi-tenant scalability in the context of AI+DLT-enhanced orchestration. **Measurement methodology**: *For baseline test (centralized orchestration)*, deploy a

				monolithic or semi-centralized orchestration setup, incrementally increase the number of active tenants with dynamic service requests, monitor system saturation point where: SLA violations increase, orchestration decision latency exceeds threshold, control plane queuing or resource conflicts occur. Record maximum number of supported tenants before degradation. For *enhanced test (Distributed AI + DLT),* replace with a distributed resource management architecture, AI agents placed at domain edges (DMOs, IDMO), DLT-based access and policy enforcement across tenant domains. Repeat the test under identical conditions. Measure the number of tenants that can be concurrently supported before the same degradation thresholds are met. Calculate scalability gain by dividing the maximum sustainable number of tenants before and after enhancement. For reporting, report scalability factor (e.g., 10x, 100x), annotate with operational boundaries such as latency, SLA compliance rate, orchestration throughput, DLT consensus delay.
#34	Reduce Open RAN real-time control loops time scales below 10 ms and 10x in NTN for	Theory/Simulation/ Emulation only	Obj#2	**Definition:** This KPI measures the ability of the system to shorten Open RAN real-time control loop execution time scales to below 10 milliseconds in terrestrial deployments (see also KPI#4 and KPI#5), and to achieve a 10x reduction of control loop latency in NTN scenarios, enabling real-time 6G control. Open RAN real-time control loops refer to closed-loop control processes operating in the Open RAN architecture, typically

	real-time 6G.			implemented via Near-Real-Time RIC xApps, that monitor network conditions, infer control decisions, and apply actions to RAN elements (e.g., scheduling, power control, beam management). Control loop time scale refers to the elapsed time between: (i) observation or measurement collection from the RAN, (ii) decision making by the control function, and (iii) enforcement of the control action on the RAN. Below 10 ms (terrestrial target) refers to UNITY-6G-defined quantitative target indicating that the end-to-end real-time control loop latency in terrestrial Open RAN deployments must be less than 10 milliseconds, enabling fine-grained and responsive 6G radio control. 10x reduction in NTNs is a relative improvement target indicating that, in NTN scenarios (e.g., LEO satellites), the real-time control loop latency achieved by the proposed solution should be at least ten times lower than a baseline NTN control loop implementation without optimization. Real-time 6G is 6G operational modes requiring ultra-low-latency, highly adaptive radio control across heterogeneous terrestrial and non-terrestrial segments. This KPI captures both absolute latency reduction (sub-10 ms) and relative improvement (10x) across different network domains. **Standards Used:** No single standard mandates both the sub-10 ms and 10x targets but O-RAN architecture

				specifications (WG1, WG2, WG3) define Near-RT RIC control loops operating in the 10 ms–1 s time scale, providing the baseline context for latency reduction. The sub-10 ms and 10x improvement targets are UNITY-6G requirements. **Measurement Methodology:** This KPI will be evaluated by comparing real-time control loop latencies under baseline Open RAN operation versus optimized, integrated real-time control. For baseline measurement, deploy standard Open RAN real-time control loops in terrestrial and NTN scenarios and measure end-to-end control loop latency (observation => decision => action). To enable optimized real-time control, introduce architectural enhancements such as edge-hosted xApps, AI-assisted inference, DT and AI-aided prediction, optimized E2 signaling, and NTN-aware control placement. For re-measuring control loop time scales, measure latency again under identical traffic and network conditions. For computing KPI values, verify that terrestrial control loops operate below 10 ms and compute the relative latency reduction in NTN scenarios and verify ≥10x improvement. For cross-scenario validation, repeat measurements across different load levels, mobility patterns, and TN–NTN configurations. A simplified logical flow is: Measure baseline control loop latency Apply real-time 6G optimizations

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				Measure new latency Compare Validate sub-10 ms and 10x targets
#35	Improve NTN reliability from 1-10⁻³ to 1-10⁻⁴	Theory/Simulation/ Emulation only	Obj#2	**Definition**: This KPI measures the improvement in reliability of 5G NTN by reducing the Packet Error Rate (PER) from a baseline value of 10^{-3} to a target value of 10^{-4} under representative operational conditions. 5G NTN refers to 5G network deployments that incorporate non-terrestrial components such as Low Earth Orbit (LEO) satellites, Medium/Geostationary Earth Orbit (MEO/GEO) satellites, or High-Altitude Platform Stations (HAPS), as specified in 3GPP NTN architectures. Reliability is here referred to the probability that data packets are delivered correctly over the communication link. In this KPI, reliability is quantified using the PER. PER is the ratio between the number of lost packets and the total number of transmitted packets over a defined observation interval. Improvement from $1\text{-}10^{-3}$ to $1\text{-}10^{-4}$ is a quantitative target indicating a tenfold (10x) reduction in packet losses, corresponding to a significant enhancement in link reliability. This improvement reflects the ability of the system to support more reliable 5G NTN services, relevant for delay- and reliability-sensitive applications. This KPI focuses on link-layer and system-level reliability, independent of higher-layer retransmission mechanisms unless explicitly stated.

				Standards Used: The baseline PER of 10^{-3} reflects commonly assumed NTN operating conditions, while the target PER of 10^{-4} is a UNITY-6G level requirement **Measurement Methodology**: This KPI is evaluated by comparing PERs measured in baseline 5G NTN operation versus enhanced operation enabled by the proposed techniques. For baseline measurement, operate a representative 5G NTN system using standard configurations and baseline link adaptation mechanisms, measure the PER over a statistically significant observation period, confirm that the baseline PER is approximately 10^{-3}. To enable reliability enhancement mechanisms, apply advanced techniques such as improved link adaptation, predictive channel estimation, AI-assisted resource management, DT–assisted optimization, or proactive interference mitigation. Re-run the same traffic and channel scenarios to keep identical traffic patterns, channel conditions, and mobility profiles to ensure fair comparison. Measure improved PER by recording the PER under enhanced operation and verifying whether the PER reaches or improves upon the target value of 10^{-4}. To validate consistency, repeat measurements across multiple scenarios (e.g., different elevations angles, mobility speeds, weather conditions) to ensure robustness and statistical validation. A simplified logical flow is:

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				Measure baseline PER Enable reliability-enhancing mechanisms Measure PER again Compare results Verify reduction from 10^{-3} to 10^{-4}
#43	Increase integrated network energy efficiency by a factor of 5 through distributed AI techniques, semantic communications, renewable energy usage, proactive strategies for resource allocation, energy aware CNF placement and task offloading, and energy aware scheduling of AI training and inference.	Theory/Simulation/ Emulation only	Obj#6	**Definition:** This KPI measures the overall improvement in integrated network energy efficiency (EE), defined as the amount of useful service delivered per unit of energy consumed (e.g., bits/Joule or tasks/kWh), achieved through the coordinated application of multiple techniques spanning AI, communications, orchestration, and energy systems. Integrated network energy efficiency considers the end-to-end energy cost of operating a multi-domain network system, including RAN, core, edge, and data centers, computational and networking functions (e.g., CNFs), AI workloads (training and inference), energy infrastructure (e.g., renewable energy integration, battery systems). Factor of 5 increase refers to a 5× improvement in EE compared to a project-defined baseline (e.g., existing 5G architecture without energy optimizations or AI-based scheduling). T*echniques* contributing to this KPI include: distributed AI- in-network intelligence reducing control/data overhead and enabling localized optimization, semantic communications- transmitting only semantically relevant information, reducing payload and processing energy, renewable energy usage, utilizing solar, wind, or

				microgrid-based sources to reduce dependence on carbon-intensive energy, proactive resource allocation- forecast-driven, adaptive scheduling of workloads and services based on predicted demand, energy-aware CNF placement and offloading, locating functions or offloading tasks to nodes with better energy profiles and energy-aware AI training/inference scheduling, timing AI workloads to align with energy availability and minimizing redundant computations **Standards Used:** There is no single global standard that defines a 5x increase in network energy efficiency. The target is qualitatively justified by UNITY-6G-level requirements showing that coordinated, multi-layer energy-aware strategies can lead to order-of-magnitude improvements in specific contexts (e.g., AI offloading, semantic compression, green energy prioritization). **Measurement methodology**: *For baseline setup (non-optimized system),* deploy a reference architecture with standard service workloads (e.g., AI inference, video delivery, control loops) using default scheduling and infrastructure. Measure, total energy consumed (in kWh or Joules), service output (e.g., bits delivered, inferences completed, SLAs met), energy efficiency as output per unit energy (e.g., bits/Joule). For *optimized setup (with energy-aware enhancements),* apply the project's enhancements, enable distributed AI agents, activate semantic-aware communication

				modules, integrate renewable energy with energy-aware placement, schedule AI and service tasks based on energy availability, and rerun the same service scenarios. For efficiency comparison, compute energy efficiency (service output divided by total energy consumed) for both setups and calculate improvement factor. For reporting, report energy efficiency values for each domain (RAN, edge, core, AI layer), show overall end-to-end EE gain (target: ≥ 5x), include breakdown of contribution from each mechanism (AI, CNF placement, semantic comms, etc.), validate that service SLAs remain satisfied (no degradation of QoS while saving energy).
#44	Increase by at least 20% the ratio of green energy consumed by the network through thanks to awareness of spatio-temporal patterns of renewable energy production and close cooperation	Theory/Simulation/ Emulation only	Obj#6	This KPI is the same with KPI#14 but instead of PoC level achievements, it works on theory, simulation and emulation level to achieve the target KPI.

	with smart grid operators.			

3.2.4 Use Case #1 KVIs

We have defined a number of KVIs that are listed in the table below:

KV as criterion and goal	KV as outcome	Use case KVIs	Target
Improved safety in case of emergency	KV: Improved response times for mission critical services and emergency services provided by multiple operators. Stakeholder: PPDR stakeholders Effect on: Process	Emergency latency time – Process	% decrease compared to current
Personal health and protection from harm	KV: Miscoordination/threat of human life caused by service outages (e.g., caused by conflicting resource allocation management processes, etc.) Stakeholder: Citizens Effect on: State of Being	Number of service outages – Event	% decrease compared to current

3.2.5 Use Case #1 Mapping Requirements to KPIs

KPI\ Requirement	#14	#15	#16	#17	#18	#21	#33	#34	#35	#43	#44
Req-UC1-01											
Req-UC1-02											
Req-UC1-03											
Req-UC1-04											
Req-UC1-05											

Req-UC1-06						■					
Req-UC1-07					■						
Req-UC1-08		■	■		■						
Req-UC1-09					■			■			
Req-UC1-10					■				■		
Req-UC1-11	■	■	■							■	
Req-UC1-12				■		■	■				
Req-UC1-13						■	■				
Req-UC1-14					■						
Req-UC1-15					■						
Req-UC1-16					■			■		■	■
Req-UC1-17					■	■	■		■		
Req-UC1-18						■					

3.3 USE CASE #2 - REAL-TIME XR/HOLOGRAPHIC COMMUNICATION

3.3.1 Use Case #2 Description

The "Immersive Experience with Real-time XR/Holographic Communications" use case within UNITY-6G envisions a next-generation communication platform capable of supporting the rapidly growing demand for immersive, interactive, and intelligent experiences while ensuring sustainability and energy efficiency. It focuses on enabling seamless, multi-user XR collaboration through Hololight Space, a high-performance industrial XR application, integrated into a semantic-aware 6G network that intelligently manages and adapts communication and compute resources in real time as illustrated in Figure 3-4.

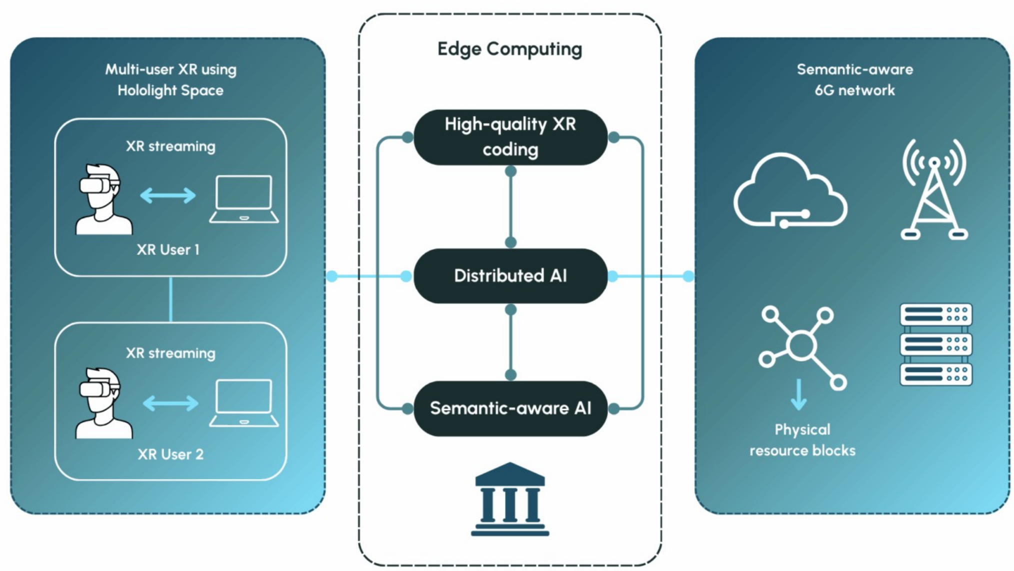

Figure 3-4 Use Case #2

Background

Emerging industrial and collaborative applications increasingly demand real-time visualization and interaction with high-fidelity 3D holographic content. Traditional 2D tools and communication methods fail to deliver spatial awareness and shared context, which limits efficiency and innovation. Emerging XR (Extended Reality) technologies bridge this gap by enabling spatially immersive, interactive 3D environments where users can engage with DTs, holograms, and live data overlays. Traditional networks lack the intelligence and flexibility to handle the large data volumes and ultra-low latency required for such immersive XR experiences. Semantic-aware integrated 6G networks address this challenge by combining AI, context-aware computing, and edge-cloud orchestration to deliver communication that adapts to the meaning and priority of the transmitted information. Through this intelligent approach, UNITY-6G enables optimized resource usage, low-latency transmission, and high reliability, critical for mission-sensitive industrial and collaborative XR operations.

Motivation

The motivation behind this use case is to demonstrate how UNITY-6G's intelligent, semantic-aware 6G network architecture can empower real-time multi-user XR collaboration through seamless orchestration of both application and network layers. The goal is to go beyond traditional QoS mechanisms by enabling semantic understanding and dynamic adaptability within the network, prioritizing XR content based on its context and criticality. UNITY-6G aims to empower industries with tools for immersive training, remote collaboration, maintenance, and design, where multiple users can interact with shared holographic environments as if co-located. With smart orchestration, adaptive streaming, and dynamic allocation of compute and network resources, the system aims to provide high-quality, low-latency, and energy-efficient immersive communication across industrial environments.

Objective

The primary objective is to design, integrate, and validate a next-generation XR communication framework where the Hololight Space XR application operates over a semantic-aware 6G network to support real-time collaboration across multiple sites. This involves implementing XR orchestration with adaptive streaming, network orchestration driven by real-time XR performance metrics, and dynamic resource allocation of compute and connectivity resources to maintain optimal performance. The use case will further evaluate semantic-based orchestration mechanisms, verify service integration within UNITY-6G's SBA and DT framework, and demonstrate how such intelligent co-optimization can ensure both user experience and sustainability. The use of edge computing, distributed AI, and semantic-aware orchestration allows the system to continuously balance performance and sustainability in demanding industrial scenarios.

Innovation

The innovation of this use case lies in its integration of semantic-aware 6G orchestration, cross-domain optimization, and real-time XR performance feedback loops, ensuring efficient operation without compromising quality. The system leverages AI-driven analytics to interpret the meaning and urgency of transmitted data, allowing dynamic network reconfiguration to maintain low latency and high visual fidelity. By combining application-layer intelligence with network-level orchestration, UNITY-6G creates a closed-loop optimization cycle that adapts automatically to user behaviour and session context. Furthermore, mobile high-quality holographic content enables 3D information transmission with realistic fidelity, while flexible CNF/task placement across edge and cloud improves scalability and sustainability. These innovations collectively establish UNITY-6G as a pioneering platform for adaptive XR streaming, low-latency communication, and intelligent orchestration, paving the way for sustainable, globally connected industrial ecosystems.

Industry Relevance and Impact

This use case has wide applicability across industrial domains. In manufacturing, teams can collaboratively inspect holographic 3D models of machinery; in energy and utilities, technicians can conduct real-time predictive maintenance on remote assets; in logistics, planners can visualize warehouse operations using DTs; and in smart maintenance, XR-guided interventions can be performed with remote expert assistance. UNITY-6G's intelligent orchestration ensures that such applications maintain stable performance even in distributed and resource-constrained environments. The broader impact includes improved collaboration, operational efficiency, reduced energy consumption, and enhanced scalability demonstrating how semantic-aware 6G infrastructure and XR applications together can drive the next wave of sustainable, intelligent industrial communication.

3.3.2 Use case #2 Requirements

The requirements section has been divided into three specific phases: preparation, deployment and operation as given in Figure 3-4.

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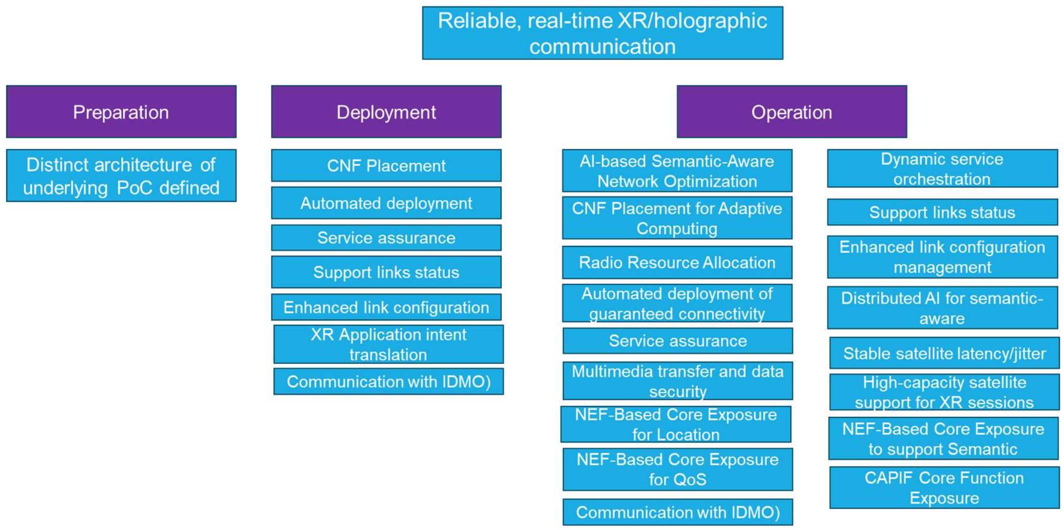

Figure 3-4 Use-case #2 requirements divided by the stages

The preparation phase involves the initial setup of the XR application, network configurations, and semantic-aware parameters. This phase includes preparing the environment, defining performance requirements (latency, bitrate, resource thresholds), configuring edge/cloud nodes, and onboarding all components into the UNITY-6G SBA to ensure they are ready for deployment. The deployment phase includes deploying XR streaming pipelines, enabling orchestration logic for compute/network resource allocation, connecting edge/cloud components, and ensuring secure, stable connectivity between all participating sites. Lastly, the operation phase involves the real-time execution of the XR holographic collaboration session. This phase includes dynamic resource allocation, adaptive XR streaming, continuous monitoring of XR metrics (latency, stability, bandwidth), semantic-aware optimisation, and multi-user coordination. The system operates autonomously to ensure a high-quality, low-latency immersive experience during industrial use.

Preparation

ID	Req-UC2-01	Priority	MUST
Name	Distinct architecture of underlying PoC defined		
Description/ Rationale	KEY provides tools that enable measurement of performance metrics in this use case. In order to understand how these tools will be implemented, the PoC implementation procedures and what interfaces will be available and required for the measurement in the final system must be well defined.		
Dependency	Requires well defined PoC setup and architecture		

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Traceability (Backward)	None
Traceability (Forward)	Connected to KEY planning of tools and interfaces to be used for measurement
UNITY-6G components	• Measurement tools
Linked KPIs	• KPI#24: Decrease end-to-end message delivery latency and increase maximum message publish throughput in SBA service bus in integrated network scenarios. • KPI#25: Increase service availability and reliability. • KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM

ID	Req-UC2-02	Priority	MUST
Name	Define underlying PoC implementation		
Description/ Rationale	SRS provides a RAN implementation (CU/DU) enabling AI-driven semantic-aware communication, flexible resource allocation (E2SM-RC). In order to understand its integration to the other PoC components, as well as any possible missing feature, PoC implementation must be well defined (e.g., specific components interacting with the RAN and interfaces used to do so, interfacing and RAN feature requirements, hardware it will be deployed in, etc.)		
Dependency	Requires well defined PoC setup and architecture		
Traceability (Backward)	srsRAN features (initial software release on project repository)		
Traceability (Forward)	Definition of RAN extensions and integration tasks (T3.1)		
UNITY-6G components	• 5G RAN (CU/DU)		
Linked KPIs	• KPI25: Increase service availability and reliability.		

Deployment

ID	Req-UC2-03	Priority	MUST
Name	CNF Placement for Adaptive Computing Resource Management		

Description/ Rationale	Real-time XR services require low-latency compute resources (e.g., rendering, encoding) to be deployed as close as possible to end users. UNITY-6G must dynamically place and migrate CNFs across edge/cloud domains using AI models that account for computing load, energy constraints, user density, and network state.
Dependency	Requires orchestration framework, telemetry inputs, and prediction engines for workload and demand forecasting.
Traceability (Backward)	-NA-
Traceability (Forward)	Feeds into latency-sensitive service orchestration, predictive load balancing, and energy-aware CNF migration policies.
UNITY-6G components	• Edge-cloud orchestration framework • CNF lifecycle manager • AI-based placement advisor (AE/DE) • MS for compute/resource metrics
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design, • KPI#40: Increase edge computational resource in the cloud by 40%

ID	Req-UC2-04	Priority	MUST
Name	Automated deployment of guaranteed connectivity for XR/HOLO communications		
Description/ Rationale	The deployment of XR/HOLO communications must include the provision of connectivity with guarantees in an automated way		
Dependency	Requires orchestration framework, telemetry inputs, and prediction engines for workload and demand forecasting.		
Traceability (Backward)	-NA-		
Traceability (Forward)	Assurance and monitoring of the service		
UNITY-6G components	• Transport Components + WiFi TSN Components		

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Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network. • KPI#23: Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements • KPI#25: Increase service availability and reliability.

ID	**Req-UC2-05**	**Priority**	**MUST**
Name	Service assurance with guaranteed connectivity SLAs (latency and throughput)		
Description/ Rationale	The services provided by the XR/HOLO application must be compliant to specific latency and throughput requirements		
Dependency	Monitoring mechanisms and Programmatic Control plane devices		
Traceability (Backward)	Req-UC2-04		
Traceability (Forward)	Reconfigurability for service assurance, comiting to UNITY-6G closed loop		
UNITY-6G components	• Transport Components + WiFi TSN Components		
Linked KPIs	• KPI#24: Decrease end-to-end message delivery latency and increase maximum message publish throughput in SBA service bus in integrated network scenarios. • KPI #45: Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected.		

ID	**Req-UC2-06**	**Priority**	**MUST**
Name	Support links status		
Description/ Rationale	UNITY-6G must enable monitoring information for the application level including latency, jitter, packet loss		
Dependency	-NA-		
Traceability (Backward)	-NA-		
Traceability (Forward)	Reliable link utilization status		

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UNITY-6G components	• Unity AI-agents for the transport domain
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design. • KPI#25: Increase service availability and reliability. • KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM • KPI#37: Guarantee 99.99999% service continuity through AI-driven proactive management of cloud-native services. • KPI#38: Reduce Operation expenditure (OPEX) by 30% due to the automation of service management and increase in link utilization (via planning annual frequency licensing).

ID	Req-UC2-07	Priority	MUST
Name	Enhanced link configuration management		
Description/ Rationale	UNITY-6G must support high-level link definition (semantic) with admission control and SLA. In case of a problem, the link will be rerouted internally, if possible, or an alarm will be raised to higher level to reroute.		
Dependency	-NA-		
Traceability (Backward)	-NA-		
Traceability (Forward)	Reconfigurability for service assurance, committing to UNITY-6G closed loop		
UNITY-6G components	• Unity AI-agents for the transport domain		
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design. • KPI#25: Increase service availability and reliability. • KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM.		

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	• KPI#37: Guarantee 99.99999% service continuity through AI-driven proactive management of cloud-native services. • KPI#38: Reduce Operation expenditure (OPEX) by 30% due to the automation of service management and increase in link utilization (via planning annual frequency licensing).

ID	**Req-UC2-08**	**Priority**	**MUST**
Name	XR Application intent translation and resources allocation automation		
Description/ Rationale	UNITY-6G platform must understand the intents and requirements for XR applications deployments and allocate the resources to answer their requirements. It must have a multi-agent architecture for the automation of XR applications deployments.		
Dependency	Linked to IDMO in the UNITY-6G architecture.		
Traceability (Backward)	Intent based management TMforum and 3GPP.		
Traceability (Forward)	-NA-		
UNITY-6G components	• IDMO (intent manager).		
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network.		

ID	**Req-UC2-09**	**Priority**	**MUST**
Name	Communication with cross-domain orchestrator (IDMO) to maintain XR SLA.		
Description/ Rationale	The Hololight Space XR application running on server infrastructure must communicate the SLA i.e., required network and compute resources and services for handling the traffic. IDMO will respond with satisfying or not satisfying the IDMO. Based on the response, Hololight Space app will adjust SLA.		
Dependency	Linked to communication with IDMO.		
Traceability (Backward)	Derived from the need to run high-fidelity XR holograms via streaming under specific network conditions.		
Traceability (Forward)	Enables adaptive streaming, improved congestion control and dynamic resource allocation		

UNITY-6G components	• IDMO
Linked KPIs	• KPI#25: Increase service availability and reliability. KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM

Operation

ID	Req-UC2-10	Priority	MUST
Name	AI-based Semantic-Aware Network Optimization for Context-Aware Resource Allocation		
Description/ Rationale	To support real-time XR and holographic applications, UNITY-6G must use semantic-aware AI models to dynamically analyse application-level data (e.g., content type, user interaction) and adapt network behaviour accordingly. This allows for fine-grained, context-aware resource allocation, optimizing QoE, reducing unnecessary traffic, and meeting stringent SLA requirements in latency and reliability.		
Dependency	Requires integration of semantic extraction engines, AI/ML inference modules (AE/DE), and a semantic-aware service bus for coordination across network layers.		
Traceability (Backward)	Derived from the need to optimize high-bandwidth, latency-sensitive services in immersive scenarios.		
Traceability (Forward)	Enables adaptive traffic steering, service orchestration, and intelligent compression for enhanced efficiency and responsiveness.		
UNITY-6G components	• Semantic-aware AE/DE components • AI-native service orchestration bus • xApps for context-aware traffic prioritization • Semantic encoder/decoder for XR/holography streams		
Linked KPIs	• KPI#22: Allocate 20% more network service LCM tasks, • KPI#23: Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements, • KPI#25: Increase service availability and reliability. • KPI#45: Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected		

ID	**Req-UC2-03**	**Priority**	**MUST**
Name	CNF Placement for Adaptive Computing Resource Management		
Description/ Rationale	Real-time XR services require low-latency compute resources (e.g., rendering, encoding) must be deployed as close as possible to end users. UNITY-6G will dynamically place and migrate CNFs across edge/cloud domains using AI models that account for computing load, energy constraints, user density, and network state.		
Dependency	Requires orchestration framework, telemetry inputs, and prediction engines for workload and demand forecasting.		
Traceability (Backward)	NA		
Traceability (Forward)	Feeds into latency-sensitive service orchestration, predictive load balancing, and energy-aware CNF migration policies.		
UNITY-6G components	• Edge-cloud orchestration framework • CNF lifecycle manager • AI-based placement advisor (AE/DE) • MS for compute/resource metrics		
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design, • KPI#40: Increase edge computational resource in the cloud by 40%		

ID	**Req-UC2-11**	**Priority**	**MUST**
Name	Radio Resource (e.g. Physical Resource Blocks (PRBs)) Allocation Based on Network Conditions		
Description/ Rationale	To ensure uninterrupted XR/holographic communication, PRBs must be dynamically assigned based on network load, user mobility, and real-time performance monitoring. UNITY-6G will utilize AI-driven models deployed in the RAN (via xApps/rApps) to predict and allocate optimal PRBs for delay-sensitive and high-throughput flows.		
Dependency	Depends on near-real-time RIC integration, telemetry from RAN nodes, and AI-based prediction/optimization models.		

Traceability (Backward)	-NA-
Traceability (Forward)	Supports service continuity, adaptive handovers, and capacity maximization for XR users.
UNITY-6G components	• Near-RT RIC with AI xApps • AI-enhanced PRB allocation module • Radio Monitoring and AE (AE/MS) • Feedback loop to Service Orchestrator
Linked KPIs	• KPI#20: Increase link utilization from 40% to 80%

ID	**Req-UC2-04**	**Priority**	**MUST**
Name	Automated deployment of guaranteed connectivity for XR/HOLO communications		
Description/ Rationale	The deployment of XR/HOLO communications must include the provision of connectivity with guarantees in an automated way		
Dependency	Requires orchestration framework, telemetry inputs, and prediction engines for workload and demand forecasting.		
Traceability (Backward)	-NA-		
Traceability (Forward)	Assurance and monitoring of the service		
UNITY-6G components	• Transport Components + Wi-Fi TSN Components		
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network. • KPI#23: Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements • KPI#25: Increase service availability and reliability.		

ID	**Req-UC2-05**	**Priority**	**MUST**
Name	Service assurance with guaranteed connectivity SLAs (latency and throughput)		

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Description/ Rationale	The services provided by the XR/HOLO application must be compliant to specific latency and throughput requirements
Dependency	Monitoring mechanisms and Programmatic Control plane devices
Traceability (Backward)	Req-UC2-04
Traceability (Forward)	Reconfigurability for service assurance, committing to UNITY-6G closed loop
UNITY-6G components	• Transport Components + Wi-Fi TSN Components
Linked KPIs	• KPI#24: Decrease end-to-end message delivery latency and increase maximum message publish throughput in SBA service bus in integrated network scenarios. • KPI#45: Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected.

ID	**Req-UC2-12**	**Priority**	**SHOULD**
Name	Multimedia transfer and data security		
Description/ Rationale	UNITY-6G should enable end-to-end encryption of multimedia data, both in transit and at rest, to prevent unauthorized access and ensure confidentiality.		
Dependency	By integrating semantic extraction engines, AI/ML inference modules, and a semantic-aware service bus, the system should provide a secure, efficient, and high-quality immersive experience with real-time XR/holographic communications		
Traceability (Backward)	Highly secure environment for jitter, spoofing and eavesdropping.		
Traceability (Forward)	Supports secure protocols and handle service orchestration		
UNITY-6G components	• Semantic-aware AE/DE components • AI-native service orchestration bus • Semantic encoder/decoder for XR/holography streams		
Linked KPIs	• KPI#45: Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected		

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ID	Req-UC2-13	Priority	SHOULD
Name	Dynamic service orchestration		
Description/ Rationale	The resource and QoS requirements of holographic applications is dynamic due to the dynamic nature of system states including user traffic. UNITY-6G platform should implement dynamic orchestration procedures such as adaptive resource allocation to comply with real-time user requirements without resource overprovisioning.		
Dependency	Requires resource utilisation metrics, cloud-native infrastructure, and enabling interfaces for the service orchestration platform to communicate with the underlying infrastructure and the holographic applications.		
Traceability (Backward)	Connected with the need to achieve flexible resource allocation to comply with SLA requirements of XR/Holographic applications under resource constrained and dynamic network scenarios.		
Traceability (Forward)	Facilitates flexible resource allocation and proactive service orchestrations to achieve SLA requirements with minimal resource consumption overhead.		
UNITY-6G components	• AE, MS, Orchestration platform, Cloud-native infrastructure		
Linked KPIs	• KPI#25: Increase service availability and reliability.		

ID	Req-UC2-06	Priority	MUST
Name	Support links status		
Description/ Rationale	UNITY-6G must enable monitoring information for the application level including latency, jitter, packet loss		
Dependency	-NA-		
Traceability (Backward)	-NA-		
Traceability (Forward)	Reliable link utilization status		
UNITY-6G components	• UNITY-6G AI-agents for the transport domain		
Linked KPIs	• KPI#19: Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design.		

	• KPI#25: Increase service availability and reliability. • KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM • KPI#37: Guarantee 99.99999% service continuity through AI-driven proactive management of cloud-native services. • KPI#38: Reduce Operation expenditure (OPEX) by 30% due to the automation of service management and increase in link utilization (via planning annual frequency licensing).

ID	**Req-UC2-07**	**Priority**	**MUST**
Name	Enhanced link configuration management		
Description/ Rationale	UNITY-6G must support high-level link definition (semantic) with admission control and SLA. In case of a problem, the link will be rerouted internally, if possible, or an alarm will be raised to higher level to reroute.		
Dependency	-NA-		
Traceability (Backward)	-NA-		
Traceability (Forward)	Reconfigurability for service assurance, committing to UNITY-6G closed loop		
UNITY-6G components	• Unity AI-agents for the transport domain		
Linked KPIs	• KPI#19**:** Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design. • KPI#25**:** Increase service availability and reliability. • KPI#36**:** Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM. • KPI#37: Guarantee 99.99999% service continuity through AI-driven proactive management of cloud-native services. • KPI#38: Reduce Operation expenditure (OPEX) by 30% due to the automation of service management and increase in link utilization (via planning annual frequency licensing).		

ID	Req-UC2-14	Priority	SHOULD
Name	Distributed AI for semantic-aware traffic management and resource allocation in O-RAN setup		
Description/ Rationale	Proper operation of real-time XR/holographic communication requires intelligent traffic management in the network to fulfil the throughput or latency requirements and to adapt to dynamic load changes. To support it UNITY-6G should use semantic-aware AI tools, accounting for the application-level and link-level information to perform intelligent traffic management and resource allocation in O-RAN deployment (using rApps and xApps).		
Dependency	Requires integration of semantic extraction engines, including an interface with near-RT RIC or Non-RT RIC, telemetry from RAN nodes, and AI-based prediction/optimization models.		
Traceability (Backward)	Is linked with the throughput and latency/jitter requirements in highly variable wireless environments and the need for agility in traffic management		
Traceability (Forward)	Supports adaptive traffic steering, service continuity, and intelligent compression.		
UNITY-6G components	• AI xApps and rApps • Semantic-aware AE/DE and RAN MS • Semantic encoder/decoder for XR/holography streams • Feedback loop to Service Orchestrator		
Linked KPIs	• KPI#23: Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements, • KPI#45: Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected		

ID	Req-UC2-15	Priority	SHOULD
Name	Stable satellite latency/jitter for XR and holographic communication		
Description/ Rationale	The satellite operator shall guarantee stable latency and predictable jitter on NTN links used for XR/holographic services.		
Dependency	QoS scheduler, XR edge components.		
Traceability (Backward)	-NA-		

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Traceability (Forward)	-NA-
UNITY-6G components	• Orchestrator, NTN RAN, TN–NTN Gateway.
Linked KPIs	KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM KPI#37: Guarantee 99.99999% service continuity through AI-driven proactive management of cloud-native services.

ID	**Req-UC2-16**	**Priority**	**SHOULD**
Name	High-capacity satellite support for XR sessions		
Description/ Rationale	The satellite system shall support high-throughput XR sessions and dynamically allocate spectrum to handle multi-user holographic traffic.		
Dependency	AI traffic prediction, dynamic capacity allocation.		
Traceability (Backward)	-NA-		
Traceability (Forward)	-NA-		
UNITY-6G components	• NTN RAN, RIC xApps/rApps.		
Linked KPIs	• KPI#25: Increase service availability and reliability.		

ID	**Req-UC2-17**	**Priority**	**SHOULD**
Name	Network Exposure Function (NEF)-Based Core Exposure for Location Retrieval to Support Semantic-Aware XR/Holographic Services (EventMonitoring API)		
Description/ Rationale	NEF Location/Monitoring Event APIs should support UC2 by enabling semantic-aware functions that can correlate XR/holographic sessions with user position and mobility. This enables location-aware resource allocation, path/slice selection, and adaptation of XR content delivery while meeting stringent latency and reliability SLAs.		
Dependency	Requires a NEF-enabled 5G Stand Alone (SA) core integrated with AMF, implementation of Location/Monitoring Event API (based on 3GPP TS 29.122/29.522), secure exposure through Common API Framework (CAPIF) and, registration and management of Application Functions (AFs) callbacks.		

Traceability (Backward)	Derived from UC2 need for location-aware optimization of high-bandwidth, latency-sensitive XR/holographic services.
Traceability (Forward)	Enables location-based traffic steering, user/slice anchoring, and mobility-aware resource orchestration for XR tenants.
UNITY-6G components	• NEF location exposure (5GC service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps
Linked KPIs	• KPI#25: Increase service availability and reliability.

ID	**Req-UC2-18**	**Priority**	**SHOULD**
Name	NEF-Based Core Exposure for QoS to Support Semantic-Aware XR/Holographic Services (NEF asessionwithQoS API)		
Description/ Rationale	UNITY-6G shall expose QoS status and allow QoS/traffic influence for XR/holographic flows through NEF QoS-related APIs so that semantic-aware AE/DE and orchestration functions can detect degradation early and adapt network behavior (e.g., route, slice, bitrate) without violating SLAs. This supports fine-grained QoE optimization and efficient use of network resources.		
Dependency	Requires NEF support for QoS monitoring and traffic influence (e.g., QoS Flow/5QI modification, event subscriptions for QoS change), integration with policy control for which AFs may request influence and secure exposure via OpenCAPIF/Gateway.		
Traceability (Backward)	Derived from UC2 requirement to maintain XR QoE under varying network conditions while using semantic-aware optimization.		
Traceability (Forward)	Enables closed-loop QoS control, proactive SLA protection for XR tenants, and automated LCM actions for XR services.		
UNITY-6G components	• NEF location exposure (5GC service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps		
Linked KPIs	• KPI#25: Increase service availability and reliability.		

ID	**Req-UC2-19**	**Priority**	**SHOULD**
Name	CAPIF Core Function Exposure of Service Discovery, Publication, Invoker Management, Logging and Auditing APIs for supporting XR/Holographic communications		
Description/ Rationale	UNITY-6G shall expose Location Retrieval and QoS NEF APIs utilizing OpenCAPIF to AFs. This requirement can support UC#2 that will need to discover/access/publish/call/manage the available APIs that are exposed by OpenCAPIF services.		
Dependency	Requires deployment of a CAPIF Core Function / OpenCAPIF Gateway that implements the 3GPP TS 23.222 service APIs, registration of the NEF QoS and Location APIs as CAPIF provider services with associated OpenAPI descriptions and reachable runtime endpoints, onboarding of UC2 Application Functions (XR backend, orchestrator, AE/DE, xApps/rApps) as CAPIF API Invokers with proper authentication/authorization and callback reachability, and integration with UNITY's SBA/service bus.		
Traceability (Backward)	Derived from UC2 need for standardized, secure and dynamic discovery, management and invocation of NEF Location and QoS APIs by multiple XR/holographic verticals, avoiding hard-coded NEF endpoints and enabling multi-tenant, slice-aware access to exposure capabilities.		
Traceability (Forward)	Enables automatic onboarding and discovery of network exposure APIs for UC2 applications, simplifies the integration of new AFs and services, and provides logging/auditing data that can be consumed by AE/DE and DT components for SLA verification, troubleshooting and optimization of XR/holographic services.		
UNITY-6G components	• NEF location exposure (5GC service) • OpenCAPIF Gateway layer (web service) • SBA/service bus • xApp/rApps		
Linked KPIs	• KPI#25: Increase service availability and reliability.		

ID	**Req-UC2-09**	**Priority**	**MUST**
Name	Communication with cross-domain orchestrator (IDMO) to maintain XR SLA.		

Description/ Rationale	The Hololight Space XR application running on server infrastructure must communicate the SLA i.e., required network and compute resources and services for handling the traffic. IDMO will respond with satisfying or not satisfying the IDMO. Based on the response, Hololight Space app will adjust SLA.
Dependency	Linked to communication with IDMO.
Traceability (Backward)	Derived from the need to run high-fidelity XR holograms via streaming under specific network conditions.
Traceability (Forward)	Enables adaptive streaming, improved congestion control and dynamic resource allocation
UNITY-6G components	• IDMO
Linked KPIs	• KPI#25: Increase service availability and reliability. KPI#36: Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM

3.3.3 Use Case #2 KPIs

The KPIs associated with this use case are listed in the table below:

KPIs	Description	Scenario for main KPI	Objective	Measurement Methodology
#19	Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification	PoC KPI	Obj#1	**Definition:** This KPI measures the improvement in the end-to-end reaction time and management effort required to identify, diagnose, and resolve network issues or optimization opportunities through proactive, automated actions enabled by an integrated design (e.g., AI-native RIC, DT, predictive analytics, closed-loop automation). Network *resource management time* is the total time required for the system to handle resource-related tasks, such as scheduling,

	to resolution via appropriate reconfigurations) with integrated design.			adjustment, load balancing, slice scaling, or configuration, under normal or disturbed network conditions. Management *overhead* is the operational burden measured in terms of number of manual interventions, number of signaling or management messages exchanged, or processing time consumed in orchestration/monitoring systems. This KPI focuses on reducing such overhead through integrated automation. Reaction *time* is the elapsed time between detecting a network condition (fault, congestion, degradation, energy inefficiency, conflict between xApps, anomaly event, etc.) and achieving a stable resolution through reconfiguration. Reaction time includes three phases: Identification: Detection or prediction of an event. Decision: Selection of corrective actions. Resolution: Execution of network reconfiguration until stability is restored. Proactive *actions* are actions taken before performance degradation becomes critical, enabled by prediction models, DT forecasting, or anomaly anticipation. Proactive

				actions aim to reduce both reaction time and management overhead. Integrated *design* is a unified architecture where analytics, DT models, resource orchestrators, and control loops interact cohesively (e.g., in UNITY-6G's AI-native TN-NTN management framework)**.** The KPI reflects the percentage reduction in total reaction time and management cost when using the integrated design, compared to baseline non-integrated operation. **Standards Used:** No current standard defines the exact reduction percentages for reaction time or management overhead **Measurement Methodology:** The KPI is evaluated by comparing the reaction time and management overhead of the network with and without the proposed integrated design. For baseline measurement (non-integrated design), trigger representative network events (e.g., congestion, beam misalignment, resource imbalance). Measure the time required to execute various management and orchestration actions, such as bandwidth allocation and resource scaling across RAN and xHaul domains, i.e. including time from detection => decision =>

				resolution, number of orchestration messages, manual interventions required (if any). Compute average reaction time and management overhead, To *enable integrated design (AI + DT + proactive control),* activate predictive analytics, DT forecasting, assess the impact of network automation powered by LLMs, and closed-loop automation examining how their integration influences efficiency, decision-making speed, and overall network performance, trigger the same events or run the same scenarios. To m*easure improved reaction time and overhead*, record identification, decision, and resolution times and track reductions in signalling load and orchestration processing effort. To *compute KPI improvement,* compare the integrated design performance against the baseline and express improvement as a percentage reduction. To v*alidate proactive action contribution*, repeat tests where proactive forecasting predicts events (e.g., load spikes, surges) and measure how early intervention reduces total reaction time An example simplified logical flow is:

				Run baseline scenario Measure detection-to-resolution time Enable integrated proactive design Run again Compare reductions in reaction time and overhead Extract KPI value.
#20	Increase link utilization from 40% to 80%.	PoC KPI	Obj#5	**Definition:** This KPI measures the improvement in link utilization, defined as the effective use of available link capacity for carrying useful traffic, by increasing utilization from a baseline of 40% to a target level of 80%. Link utilization is the ratio between the actual throughput of user and control traffic carried over a communication link and the maximum achievable capacity of that link under given physical and protocol constraints. Baseline utilization (40%) is the reference operating point representing current or conventional network operation, where links are underutilized due to conservative planning, static allocation, peak provisioning, or lack of coordination across domains. Target utilization (80%) is the desired operating point where the majority of available link capacity is effectively used while maintaining acceptable

				quality-of-service (QoS), reliability, and latency constraints. Increase from 40% to 80% is a UNITY-6G-defined quantitative improvement indicating a doubling of effective link utilization, achieved through advanced planning, dynamic resource management, predictive analytics, or cross-domain coordination. This KPI reflects improved efficiency of network resource usage without compromising service quality. **Standards Used**: No telecom standard mandates a specific target utilization (e.g., 80%); therefore, the numerical values are UNITY-6G-defined targets **Methodology:** For high-capacity traffic with restricted latency, one solution is to increase the number of links or the link utilizations. Record the link utilization counter when running various traffic pattern. For each traffic flow record the number of packets received, average capacity, packet loss. Run #1: using OSPF as the baseline Run #2: using dynamic routing-based AI. Compare the average link utilization and the flows statistics between the two runs.

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#22	Allocate 20% more network service LCM tasks	PoC KPI	Obj#7	**Definition:** This KPI quantifies the increase in the number of network service LCM tasks that can be concurrently and successfully handled by the orchestration system, enabled by architectural or algorithmic enhancements (e.g., AI-native orchestration, distributed task delegation, microservice-based SBA frameworks). *Network service LCM* tasks include instantiation, scaling, termination, healing, updating, and monitoring of services and network slices. These may involve chained virtual/physical functions, multi-domain orchestration, and real-time resource adaptation. *Allocate 20% more* means that, compared to a defined baseline architecture (e.g., a centralized NFV MANO system), the enhanced orchestration framework can sustain at least 20% more LCM tasks in a given time window, without exceeding thresholds for orchestration latency, SLA violations, or resource exhaustion. **Standards used**: no single standard defines the "LCM task allocation capacity" as a KPI. The 20% improvement target is based on: UNITY-6G-specific performance expectations for enhanced orchestration systems.

				Measurement Methodology: For baseline measurement (traditional orchestration setup), deploy a reference orchestration platform (e.g., centralized ETSI NFV MANO stack), simulate or generate a mix of LCM tasks (e.g., 50% instantiation, 25% scaling, 15% termination, 10% healing) over a defined time window (e.g., 10 minutes), measure total number of completed tasks, task failure rate or timeouts, orchestration latency per task. Identify the system's maximum sustainable LCM throughput without SLA violation or degradation. For enhanced setup (with UNITY-6G architecture with AI, SBA, or distributed logic), run the same workload using the enhanced orchestration platform, increase the task load incrementally. Measure until orchestration performance reaches the same thresholds as baseline. For comparison, compute the percentage increase in LCM task capacity. Ensure SLA compliance and orchestration latency remain within defined thresholds. For reporting, report achieved gain (target: ≥ 20%), disaggregate results by LCM task type (instantiation vs scaling, etc.), include metrics such as task queue latency, orchestration CPU/memory load, or concurrency profile.

#23	Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements.	PoC KPI	Obj#7	**Definition:** This KPI quantifies the effectiveness of the system in reducing communications overhead, defined as the volume of signaling, telemetry, or control traffic exchanged between system components (e.g., orchestrators, agents, controllers, service endpoints), by a factor of 10, compared to a baseline setup, without violating predefined SLA requirements. *Communications overhead* can include management/control plane traffic (e.g., intent propagation, orchestration commands), monitoring/telemetry updates (e.g., status reports, performance metrics), or synchronization and consensus messages in distributed setups (e.g., DLT logs, multi-agent decisions). *A 10× reduction* means the optimized system transmits 90% fewer overhead messages or bytes while still achieving the same operational outcome (e.g., service instantiation, reconfiguration, resource adjustment). *Maintaining SLA* requirements means that latency, throughput, availability, and reliability KPIs for the managed services remain within agreed thresholds and reduction in overhead must not compromise service performance or user experience.

				This KPI captures the benefit of applying efficient communication strategies such as hierarchical or event-driven telemetry, compressed model updates (e.g., semantic or federated learning), local decision autonomy with minimal coordination. **Standards used:** no single standard defines a quantitative target for communication overhead reduction. The *10× reduction factor* is supported by: UNITY-6G design goals (e.g., enabling lightweight orchestration over constrained or TN-NTN links), research insights from semantic-aware compression, intent compaction, or hierarchical delegation. **Measurement Methodology**: For baseline measurement (traditional architecture), use a representative service scenario (e.g., lifecycle management, slice adaptation, AI model coordination), deploy it using standard telemetry and control exchange mechanisms. Measure total volume of overhead data (in MB) or message count exchanged among components, SLA compliance metrics (e.g., latency, availability, jitter, throughput). For optimized setup (efficient communication mechanisms enabled), enable the UNITY-6G optimized features, aggregated and event-driven

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				telemetry, model or intent compression, localized control loops with periodic sync. Re-run the same scenario and measure: total overhead communication volume, SLA compliance. Compute overhead reduction using baseline and optimized overheads and ensure SLA compliance deviation is within tolerance (e.g., ≤ 1% degradation). For reporting, report average and worst-case reduction factor (target: ≥10x), SLA metrics to validate that service guarantees are preserved, optionally bandwidth savings correlated with overhead reduction.
#24	Decrease end-to-end message delivery latency and increase maximum message publish throughput in SBA service bus in integrated network scenarios.	PoC KPI	Obj#1	**Definition:** This KPI measures the improvement in the end-to-end (E2E) delivery latency, and the maximum publish throughput of messages exchanged through an SBA service bus when applied to integrated network scenarios (e.g., TN-NTN convergence, multi-domain orchestration, cloud-edge environments). End-to-End message delivery latency is the total elapsed time between the moment a message is published by a producer (e.g., network function, service, xApp/rApp, AI agent, NTN-TN devices) and the moment it is received and acknowledged by the target consumer(s) via the SBA service bus. This includes encoding,

				routing, queuing, transport, and processing delays. Maximum message publish throughput is the highest sustainable rate at which the SBA service bus can successfully process and deliver published messages without queue saturation, congestion collapse, or violations of latency requirements. Formally, throughput is measured as messages per second (msg/s). SBA service bus is the communication fabric of an SBA that allows network functions and services to interact using APIs (HTTP/2, JSON, REST, or message brokers). In 5G/6G contexts, this refers to the 3GPP SBA (core), O-RAN service bus, and extended cross-domain buses in integrated TN-NTN architectures. Integrated network scenarios are unified environments involving terrestrial and NTNs, cloud–edge split deployments, multi-domain orchestration layers, or cross-operator environments, where the SBA bus spans heterogeneous network segments. This KPI quantifies how much the integrated design improves E2E responsiveness and publish capacity

				relative to baseline SBA performance. **Standards Used:** This KPI is framed using terminology and measurement guidance from 3GPP SBA Standards, O-RAN architecture (WG1), Zero-Touch Service Management (ETSI ZSM) and CNCF Cloud Native Definition to define vocabulary, measurement units, and architectural assumptions. The improvement objective (latency reduction and throughput increase) is UNITY-6G requirement. **Measurement Methodology:** This KPI is evaluated by comparing SBA service bus performance before and after applying an integrated design (e.g., optimized routing, edge offloading, DT-informed scheduling on the SBA bus given its limited capacity, AI-based tuning, etc). To establish baseline SBA performance, deploy the SBA bus in a reference configuration (no optimizations, no integrated design, e.g. with a traditional point-to-point (P2P) communication. Measure E2E message latency under varying loads and maximum sustainable publish throughput before SLA violations or instability. Use controlled scenarios to ensure reproducibility.

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				To enable integrated network design enhancements examples include DT-assisted routing path estimation, AI-based congestion prediction, improved message broker configuration, smart batching or prioritization, TN-NTN-aware scheduling To re-run the same messaging tests, measure E2E latency across identical traffic patterns, identify new maximum publish throughput under controlled saturation testing. To *compute improvement KPIs*, compare latency reduction (%) and throughput increase (%) relative to the baseline. The KPI is satisfied if the integrated bus exhibits statistically significant and repeatable improvement. For *cross-scenario validation*, conduct tests for mixed TN–NTN paths, multi-domain orchestration, and varying message sizes. An example simplified logical flow is: Run baseline latency/throughput test Apply integrated design Run the same test Compare results Extract KPI improvements

#25	Increase service availability and reliability.	PoC KPI	N/A	**Definition**: Service availability and reliability refer to the ability of XR sessions in UC2 to meet their SLA targets, specifically: latency, packet loss rate and throughput, referred from now as "operational". Availability is defined as the percentage of time that the service is operational (Total time- Down time / Total Time) and reliability measures the consistent performance over time, using the Mean Time Between Failures: Total Operational time / Number of Times service is not operational. **Standards Used**: No standards used in this KPI **Measurement Methodology:** The Device Under Test (DUT) is configured to monitor: - Discoverability of the NEF Location API through CAPIF - Discoverability of the NEF QoS API through CAPIF The measurement process consists of two phases executed under identical traffic and environmental conditions: Run #1 Baseline: UC2 XR sessions are deployed over a common best-effort service, without SLA guarantees. SLA satisfaction

				percentages are recorded through the discoverability of CAPIF APIs Run #2*:* The same UC2 XR workload is executed again, deployed over and end to end service with SLA assurance. The same SLA satisfaction is measured. After both runs, the following comparisons are made: - Changes in discoverability of NEF QoS and Location through CAPIF The final KPI result is presented as the percentage improvement in availability and reliability when the XR service is deployed compared to the baseline.
#36	Guarantee 99.99999% service availability and reliability based on effective monitoring and LCM	Theory/Simulation/Emulation only	Obj#3	**Definition**: Service availability: The proportion of time the XR/holographic service remains operational and accessible with all required QoS guarantees. Service reliability: The probability that the service performs its required function (meeting latency, packet delivery ratio (PDR) targets) without failure over a specified period. **Standards Used**: Reliability has been defined in 3GPP URLLC for applications like remote control or industrial automation.

				Measurement Methodology: System Setup and Monitoring Initialization Launch real-time XR/holographic sessions Start continuous observability Continuous Monitoring and Fault Injection Run the XR traffic simulation continuously over an extended period Introduce load, disturbances, and random failures Measurement of Failure and Recovery Metrics The LCM monitoring system logs all service interruptions or critical KPI violations KPI Calculation and Validation Service Availability: $\left(1 - \frac{\text{Total Downtime}}{\text{Total Test time}}\right) \times 100\%$ Service Reliability: $\frac{\text{Number of correctly delivered packets}}{\text{Total packets delivered}} \times 100\%$
#37	Guarantee 99.99999% service continuity through AI-driven proactive	PoC KPI	Obj#3	**Definition:** This KPI measures the ability of the system to ensure ultra-high service continuity (99.99999%) for cloud-native network services by leveraging AI-driven proactive management mechanisms, including

	management of cloud-native services.			prediction, prevention, and automated remediation of failures. Service continuity is the capability of a service to remain available and operational without interruption over a given observation period. Service continuity is expressed as the percentage of time during which the service is delivered according to its SLA, excluding only planned maintenance windows if explicitly stated. 99.99999% service continuity (seven nines) *is* quantitative availability target corresponding to a maximum service downtime of approximately 3.15 seconds per year. This target reflects ultra-reliable operation required for mission-critical 6G services. Cloud-native services are network and service functions deployed using cloud-native principles, including containerization, microservices, service meshes, dynamic scaling, and distributed orchestration across cloud and edge environments. AI-driven proactive management is the use of AI/ML techniques (e.g., predictive analytics, anomaly detection, DT forecasting) to anticipate faults, overloads, or performance degradation before they cause service disruption, and to

				trigger automated mitigation actions (e.g., scaling, migration, reconfiguration). Guarantee refers to achieving and sustaining the defined service continuity level during controlled evaluations and representative operational scenarios, supported by proactive AI-based mechanisms rather than reactive recovery alone. This KPI captures the effectiveness of proactive, AI-enabled management in sustaining extreme service reliability in cloud-native environments. **Standards Used:** The 99.99999% continuity target is not mandated by a single telecom standard but is consistent with requirements and definitions provided by multiple standardization bodies (e.g. 3GPP Service Availability and Reliability, ETSI ZSM, O-RAN Alliance) addressing ultra-reliable services. The numerical target of 99.99999% is therefore a UNITY-6G-level requirement, justified by emerging 6G use cases (e.g., critical infrastructure, autonomous systems) and grounded in standardized definitions of availability and continuity. **Measurement Methodology:** This KPI is evaluated by comparing

				service continuity under conventional (reactive) management with continuity achieved through AI-driven proactive management of cloud-native services. Baseline measurement (reactive management), *d*eploy cloud-native services with standard monitoring and reactive recovery mechanisms, then introduce representative disturbances (e.g., load spikes, component failures, network degradation). Finally, measure total service downtime and compute baseline service continuity. To enable AI-driven proactive management, activate AI-based prediction, anomaly detection, DT-enabled forecasting, then enable automated mitigation actions (e.g., pre-emptive scaling, service migration, reconfiguration). For example, train AI-driven DRL algorithms to perform proactive management actions, such as automatically triggering scaling operations executed by the orchestrator. Run identical scenarios, re-execute the same disturbance scenarios under proactive management. Record service downtime and continuity metrics.

				Compute service continuity, calculate achieved continuity over the observation period and verify whether continuity meets or exceeds 99.99999%. Validate *stability across scenarios,* repeat measurements across multiple service types, deployment locations, and traffic conditions. An example simplified logical flow is: Measure baseline continuity Enable AI-driven proactive management Re-run failure scenarios Measure continuity Compare Verify seven-nines target
#38	Reduce Operation expenditure (OPEX) by 30% due to the automation of service management and increase in link utilization (via planning annual	Theory/Simulation/Emulation only	Obj#3	**Definition:** This KPI quantifies how much the project's integrated automation and resource-optimization mechanisms reduce OPEX for the network operator, specifically through (i) automation of service management processes and (ii) improved link utilization achieved via enhanced annual frequency licensing and planning mechanisms. Since a network that can support disaster event can be very expensive, the purpose of this KPI is

	frequency licensing).			to decrease the network cost (in planning). OPEX refers to recurring costs required to operate the network, including network monitoring and troubleshooting, manual configuration and service lifecycle management, spectrum licensing costs, energy consumption and maintenance, human labour and operational workflows. In this KPI, OPEX is particularly tied to: (a) the cost of manual or semi-automated service-management workflows, and (b) costs associated with sub-optimal link utilization and frequency licensing. 30% reduction is a UNITY-6G-defined quantitative improvement target indicating that automated service management and improved link utilization should reduce relevant OPEX categories by at least 30% compared to baseline operations. Automation of service management refers to replacement of manual or operator-driven workflows with automated or AI-driven orchestration for service creation/termination, fault management and healing, performance optimization, SLA monitoring and adjustment, cross-domain coordination.

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				Increased link utilization is enhanced efficiency in the use of licensed spectrum (e.g., microwave, satellite, mmWave[1], or 6G band allocations) achieved through better planning, dynamic adjustments, or predictive models that ensure higher traffic-carrying capacity per licensed MHz. This leads to lower per-bit cost and better amortization of licensing expenditures. Annual frequency licensing planning refers to the process by which operators negotiate or renew annual licenses for specific frequency bands. Improved link utilization allows more cost-efficient use of these licenses, reducing OPEX components tied to spectrum underutilization. The KPI reflects the combined cost reduction attributable to automation-driven labour savings and more efficient spectrum usage. **Standards Used:** No telecom standard specifies a required 30% OPEX reduction. The exact KPI threshold (30%) is a UNITY-6G requirement, aligned with achievable cost savings in automated, AI-supported 6G networks. **Measurement Methodology:** This KPI is evaluated by comparing OPEX values under baseline operations

[1] Millimeter Wave

				versus OPEX values under automated service-management and improved link-utilization scenarios. For b*aseline OPEX measurement (no automation / conventional link utilization), i*dentify relevant OPEX categories influenced by service management and spectrum utilization and measure baseline costs over a representative period: labour hours spent on service management tasks, number of manual interventions, operational inefficiencies in link utilization, annual licensing cost per effective Mbps or per MHz used. To *enable automated service management + improved link utilization, a*ctivate AI-driven orchestration, automated LCM workflows, predictive fault management, and optimized frequency planning, apply DT or AI-based forecasting to increase actual utilization of licensed bands. To measure OPEX under enhanced operation, *r*ecord the same cost categories after automation is applied. *i*nclude savings from: reduced human labour, fewer manual processes, reduced resource use from efficient planning, improved amortization of licensed spectrum.

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				To compute the OPEX reduction ratio, compare enhanced-operation OPEX to baseline OPEX. The KPI is achieved if the reduction is ≥ 30%. Compare the network design cost vs reliability between current planning tool and the enhanced suggested planning tool. To *validate across multiple operational periods*, repeat the comparison over several cycles (e.g., monthly or quarterly) to ensure consistency. An example simplified logical flow is: Measure baseline OPEX Enable automation + improved utilization Measure new OPEX Compare Extract 30% reduction KPI value
#40	Increase edge computational resource in the cloud by 40%.	Theory/Simulation/Emulation only	Obj#3	**Definition:** This KPI must be rephrased as: "*increase edge computational resource utilization by 40%*" instead of " *increase edge computational resource in the cloud by 40%*". This KPI ensures that the utilization of the edge resources (for instance edge servers) for executing computational tasks is enhanced versus the strategy of offloading everything in the cloud, to be executed centrally. Considering an

				edge/cloud continuum with a hierarchical architecture, this KPI reflects the ratio between the number of tasks that are offloaded horizontally (from edge servers to other edge servers) and the tasks that are offloaded vertically (from edge servers to the cloud). This KPI aligns with the distributed computational architecture, since offloading all the tasks to the cloud introduces delays, compromising the computational task deadlines, as well as increasing the communication overhead towards centralized points. **Standards Used:** The edge/cloud continuum concept has been described in ETSI MEC (Multi-access Edge Computing) initiative. However, no standards define the increased utilization of edge resources instead of cloud resources. A similar KPI has also been identified among ICT-52 projects in 5GPPP [21]. **Measurement Methodology**: This KPI will be measured in a simulated environment consisting of several edge and one cloud servers. Computational tasks will be generated by the IoT/end device layer (the hierarchically lower layer) and will be sent to the edge/cloud continuum for execution. The tasks (e.g., image processing, training of an ML model) will have parameters

				like deadline, size and required computational capacity. ML models that are hosted in the edge servers will decide upon executing the task locally or offloading it either to other edge servers (horizontally) or to the cloud (vertically), conforming with the task latency constraints. Then, the ratio of the offloaded tasks to the edge vs cloud will be quantified in different scenarios and topologies (for different number of edge servers, varying the network topology and the links between them, etc.). The ML-assisted offloading scheme will be compared against rule-based approaches, e.g., "execute locally" or "offload to comply with the deadline" policies.
#45	Guarantee that with semantic-aware communication, SLA guarantees and KPI requirements remain unaffected	Theory/Simulation/Emulation only	Obj#7	**Definition:** This KPI ensures that the adoption of semantic-aware communication mechanisms, which apply data abstraction, compression, and context-aware prioritization techniques, does not degrade the network's ability to meet SLA guarantees or underlying KPI thresholds. Semantic-aware communication refers to communication techniques that focus on meaning rather than raw data fidelity, using intelligent compression, selective transmission, or semantic similarity metrics to reduce transmission volume while

				preserving actionable content. Examples include object-based compression (e.g., in images, sensor streams), intent-level signalling, semantic similarity models for filtering redundant updates. SLA guarantees include specific thresholds for latency, reliability, availability, throughput, packet loss, etc., defined per service or slice and agreed upon with the tenant/user. KPI requirements refer to the technical performance indicators used to monitor service behaviour (e.g., CPU utilization, jitter, model accuracy for AI services, etc.). The term *“remain unaffected*” is operationally defined as no statistically significant degradation (e.g., within a 1% tolerance window) in the monitored SLA and KPI metrics when using semantic-aware communication, compared to standard communication protocols. **Standards Used:** As semantic-aware communication is an emerging research domain, no single standard is used, and no standards define exact SLA threshold. **Measurement Methodology:** *For baseline test (standard communication stack),* run a representative service (e.g., image/video streaming, real-time

				sensor analytics, model-in-the-loop inference) over traditional IP-based communication without semantic reduction, monitor and record SLA and KPI metrics: end-to-end latency, throughput, jitter, PER, service-specific KPIs (e.g., AI inference accuracy, control loop responsiveness). For *semantic-aware communication enabled*, repeat the same experiment, but enable semantic communication techniques: semantic compression of payloads (e.g., based on context importance), data summarization or representation (e.g., with YOLO[2]/XAI inference filters), intelligent update filtering (e.g., transmission only on semantic novelty). Measure the same SLA and KPI set. For *comparison and evaluation,* compute deviations in SLA/KPI metrics between baseline and semantic-aware setups, use statistical tests (e.g., t-test, confidence intervals) to determine whether differences fall within non-significant bounds (e.g., ≤ 1%). For reporting, present time-series plots or bar graphs comparing baseline and semantic-aware cases, report % deviation for each SLA/KPI

[2] You Only Look Once (YOLO), a computer vision algorithm that detects objects in images or videos in real time.

				metric and highlight any failure cases or thresholds exceeded.

3.3.4 Use case #2 KVIs

We have defined a number of KVIs that are listed in the table below:

KV as criterion and goal	KV as outcome	Use case KVIs	Target
Sustainable, high-performance immersive industrial operations	Reliable, real-time XR/holographic communication that improves operational safety, reduces errors, and supports energy-efficient network usage. Stakeholders: Industrial workforce, operators, infrastructure providers. Effect on: Enhanced operational efficiency, reduced downtime, improved sustainability and energy use.	Latency stability, bitrate stability, packet loss rate, continuity of connection, bandwidth utilization efficiency.	Stable immersive performance, minimal disruptions, and efficient resource usage (% optimal utilization).
Equitable and scalable multi-site immersive collaboration	Consistent, high-quality XR collaboration across distributed industrial locations, enabling remote expertise, reduced travel, and faster knowledge transfer. Stakeholders: Industrial experts, remote workers, SMEs, trainers.	Number of participating distributed industrial sites, session stability across sites, multi-user interaction quality.	Reliable collaboration across multiple sites with sustained session quality (high continuity and user experience).

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	Effect on: Improved collaboration efficiency, reduced carbon footprint, increased inclusivity and remote capability.		

3.3.5 Use Case #2 Mapping Requirements to KPIs

KPI/Requirement	#19	#20	#22	#23	#24	#25	#36	#37	#38	#40	#45
Req-UC2-01					■	■	■				
Req-UC2-02						■					
Req-UC2-03	■									■	
Req-UC2-04	■			■		■					
Req-UC2-05					■						■
Req-UC2-06	■					■	■	■	■		
Req-UC2-07	■					■	■	■	■		
Req-UC2-08	■										
Req-UC2-09						■	■				
Req-UC2-10			■	■		■					■
Req-UC2-11		■									
Req-UC2-12											■
Req-UC2-13						■					
Req-UC2-14				■							■
Req-UC2-15							■	■			
Req-UC2-16						■					

Req-UC2-17											
Req-UC2-18											
Req-UC2-19											

3.4 USE CASE #3 - DT FOR INTEGRATED 6G NETWORK EVALUATION

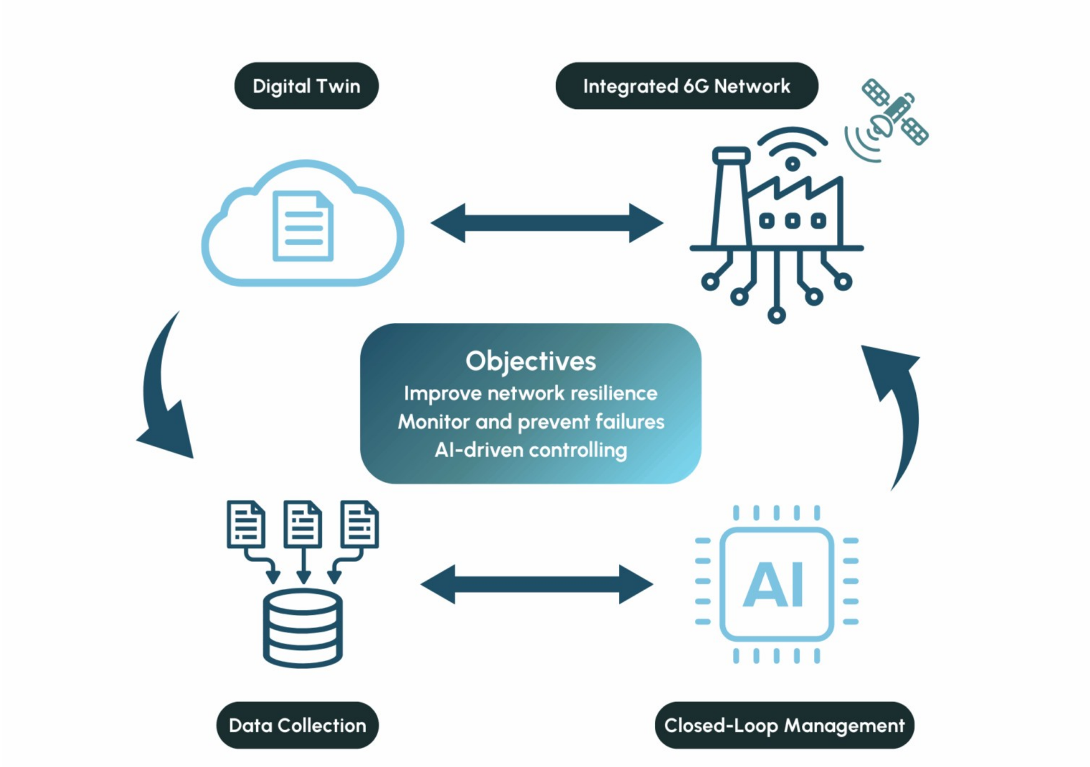

Figure 3-6 Use Case #3

3.4.1 Use Case Description

Use Case 3 establishes a DT framework designed to create a comprehensive digital replica of the entire integrated heterogeneous domain infrastructure of the UNITY-6G network. The primary motivation behind this use case is to enhance network resiliency and robustness by addressing the complexities associated with operating integrated 6G infrastructures. By modelling physical assets, including network components, equipment, and their interactions across heterogeneous domains, the DT enables proactive decision-making and predictive control, allowing operators to prevent equipment failures and optimize performance before issues impact the physical network.

Key Objectives and Functionalities

The DT serves as a tool for network management and evaluation, focusing on several critical objectives:

- **AI/ML Model Training:** It provides realistic platforms and environments for training AI/ML models, specifically facilitating online training with DRL to better fit real production networks.

- **Service Testing and Deployment:** The DT enables the rapid testing and deployment of novel 6G services, allowing operators to assess future deployment scenarios and evaluate the impact of configuration and function changes in a safe, virtual environment.
- **Preventive Maintenance:** By aggregating network-related information and generating historical data and statistics, the DT supports preventive maintenance strategies, retrieving insights about potential future problems to minimize downtime.
- **Resource Management:** It simplifies site deployment configurations and enhances the management of service resources, as well as the operation of the edge-cloud continuum.

Innovation and Impact

The novelty of this use case lies in its ability to utilize AI-driven closed-loop management, providing a proactive perspective to network operation with GenAI-enhanced data where the DT predicts future behaviours, thereby significantly improving the overall reliability, sustainability, and efficiency of the 6G network it is employed to.

3.4.2 Use Case #3 Requirements

For this use case we have specified several system requirements that are linked to KPIs in section 3.4.3. The description, their dependency and relation to KPIs are listed in Figure 3-5

.

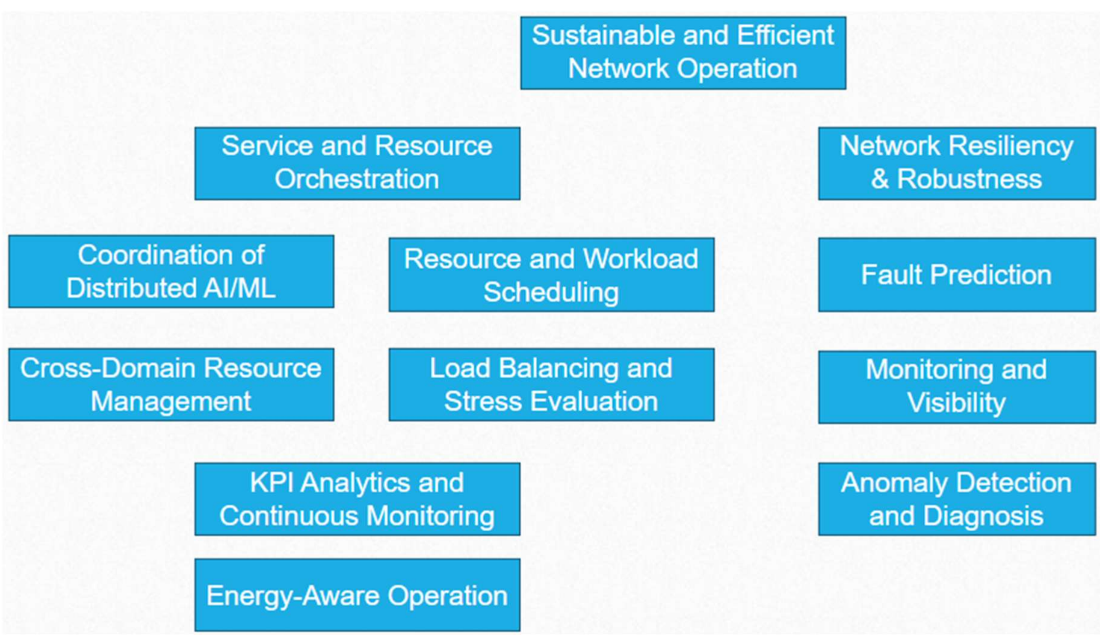

Figure 3-5 Use Case 3 topologically ordered according to the requirements

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ID	Req-UC3-01	Priority	MUST
Name	Anomaly Detection & Predictive Maintenance for Proactive Fault Management		
Description/ Rationale	The DT must continuously analyse real-time data to detect network anomalies and anticipate equipment or service degradation. By leveraging AI-driven analytics (AE/DE), UNITY-6G can proactively trigger preventive maintenance and automatic reconfiguration, minimize service downtime and improving resilience.		
Dependency	Depends on high-quality real-time data acquisition, trained AI models, and actuator mechanisms to apply corrections.		
Traceability (Backward)	Based on the goal to enable fault-tolerant, resilient integrated 6G infrastructures.		
Traceability (Forward)	Supports service continuity, fault recovery, and SLA compliance in heterogeneous environments.		
UNITY-6G components	• AE • DE • ACT components for real-time reconfiguration • DT–based anomaly simulator		
Linked KPIs	• KPI#28: An average accuracy of up to 90% in energy consumption and 80% in resource allocation compared to a testbed instance • KPI#42: DT-validated AI algorithms that do not break the time-sensitive operation when deployed in 99% of the outputs.		

ID	Req-UC3-02	Priority	MUST
Name	AI-Assisted Configuration Optimization for Rapid Site Deployment		
Description/ Rationale	UNITY-6G aims to accelerate network site rollout and reconfiguration by simulating deployments through the DT and applying AI-assisted optimization. The system should evaluate optimal parameter settings (e.g., topology, power, CNF placement) before physical changes, thus minimizing errors, deployment time, and energy consumption.		
Dependency	Relies on a feedback loop between the DT, orchestrator, and AI models trained on historical and simulated data.		

Traceability (Backward)	Driven by the need to scale integrated 6G deployments efficiently and cost-effectively.
Traceability (Forward)	Feeds into network lifecycle management, energy-aware planning, and zero-touch deployment workflows.
UNITY-*6G components*	• DT configuration sandbox • AI optimizers for deployment parameters • LCM and orchestration interfaces • CNF/service configuration manager
Linked KPIs	• KPI#31: Reduce service recovery time below 180s. • KPI#41; Reduction of 70% of deployment time of AI-based resource/energy management algorithms

ID	**Req-UC3-03**	**Priority**	**MUST**
Name	Actionable on-demand DT		
Description/ Rationale	To have a DT that can operate with on-demand actions, by supporting standard interfaces		
Dependency	Available physical network and other components in the UNITY-6G architecture		
Traceability (Backward)	N/A		
Traceability (Forward)	Apply predicted actions over the specific domain		
UNITY-*6G components*	• DT + Transport Components | Functional: MS, AE, DE and ACT		
Linked KPIs	• KPI#6: Decrease service creation and termination time (PoC#2, ES#3). • KPI#26: Increase the ratio of service management and LCM tasks resolved by local AE/DE components		

ID	**Req-UC3-04**	**Priority**	**SHOULD**
Name	NEF-Based Exposure of Location / Monitoring Events for DT Ingestion		

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Description/ Rationale	The DT needs accurate information on UE and device positions, mobility patterns and area-level activity to mirror the real integrated 6G network. NEF Location/Monitoring Event APIs shall expose UE and device location events to the DT data ingestion pipeline so that the DT can reconstruct spatial distributions of users, evaluate placement and routing strategies, and assess resilience and sustainability under different mobility and disaster/traffic scenarios.
Dependency	Requires a 5G SA core with NEF integrated to AMF (and, when required, Location Management Function (LMF) or equivalent) and support for Location/Monitoring Event APIs as per 3GPP TS 29.122/29.522, together with secure exposure via CAPIF/OpenCAPIF or equivalent, and data connectors from NEF/CAPIF into the UC3 DT service.
Traceability (Backward)	Derived from UC3 need to build a realistic, continuously updated network DT that captures spatial user distribution and mobility across TN/NTN, xHaul and edge-cloud domains.
Traceability (Forward)	Enables DT scenarios such as location-aware what-if experiments, impact assessment of mobility on SLAs, and evaluation of placement/orchestration policies under varying user distributions.
UNITY-6G components	• NEF Location exposure (5GC) • DT data ingestion and storage • AE/DE using DT outputs • SBA/service bus • CAPIF/OpenCAPIF if used for DT subscriptions.
Linked KPIs	• KPI 6: Decrease service creation and termination time (PoC#2, ES#3). • KPI 30: Decrease service creation and termination time (PoC#1, ES#3).

ID	**Req-UC3-05**	**Priority**	**SHOULD**
Name	NEF-Based Exposure of QoS Monitoring and Influence for DT Evaluation		
Description/ Rationale	The DT must ingest flow-level QoS information (latency, throughput, loss, QoS flows/5QIs) and, in some scenarios, emulate the effect of QoS policies and traffic influence. NEF QoS monitoring and traffic-influence APIs shall expose QoS status and policy decisions to the DT so that UC3		

	can evaluate the impact of AI/ML algorithms, energy-aware routing and resource sharing on service KPIs and SLAs across integrated domains.
Dependency	Requires NEF support for QoS monitoring and traffic influence (as defined in TS 29.522), integration with PCF/SMF/UPF, and data export from NEF into the DT (via CAPIF, message bus or dedicated collector), including appropriate anonymisation where needed.
Traceability (Backward)	Derived from UC3 objective to use DT to study cross-domain performance and sustainability trade-offs, which requires end-to-end QoS data and the ability to emulate different QoS policies.
Traceability (Forward)	Enables DT-based evaluation of routing and placement strategies, prediction of QoS violations, and validation of closed-loop control policies before deployment in the real network.
UNITY-6G components	• NEF Location exposure (5GC) • DT data ingestion and storage • AE/DE using DT outputs • SBA/service bus • CAPIF/OpenCAPIF if used for DT subscriptions.
Linked KPIs	• KPI 6: Decrease service creation and termination time (PoC#2, ES#3). • KPI 30: Decrease service creation and termination time (PoC#1, ES#3).

ID	**Req-UC3-06**	**Priority**	**SHOULD**
Name	CAPIF Core Function Exposure of Service Discovery, Publication, Invoker Management, Logging and Auditing APIs for Management of DT-Relevant Exposure APIs		
Description/ Rationale	UNITY-6G should utilise CAPIF/OpenCAPIF so that the UC3 DT and related analytics components can systematically discover, register to and manage NEF Location, NEF QoS and other exposure APIs (e.g., RAN/transport metrics) needed for building and running the DT. Using CAPIF ensures a uniform, standards-based way to onboard the DT as an API Invoker, manage subscriptions, and access invocation logs for DT validation.		

Dependency	Requires a CAPIF Core/OpenCAPIF instance with Discovery, Publish, API_Invoker_Management, API_Provider_Management and Logging/Auditing services (3GPP TS 23.222), registration of UC3-relevant exposure APIs (NEF Location, NEF QoS, possibly others) as CAPIF provider services with OpenAPI descriptions, and onboarding of the DT service and AEs as CAPIF API Invokers.
Traceability (Backward)	Derived from UC3 requirement to integrate heterogeneous exposure sources into a single DT pipeline and from UNITY's objective to use standardised exposure and API management frameworks.
Traceability (Forward)	Enables scalable integration of new exposure sources into the DT, simplifies DT deployment across PoCs, and provides invocation logs/audit trails useful for validating DT accuracy and assessing alignment between twin and real network.
UNITY-6G components	• NEF Location exposure (5GC) • DT data ingestion and storage • AE/DE using DT outputs • SBA/service bus • CAPIF/OpenCAPIF if used for DT subscriptions.
Linked KPIs	• KPI 6: Decrease service creation and termination time (PoC#2, ES#3). • KPI 30: Decrease service creation and termination time (PoC#1, ES#3).

ID	**Req-UC3-07**	**Priority**	**SHOULD**
Name	GenAI-Driven Synthetic Data Creation for Model Training		
Description/ Rationale	The DT may utilize GenAI to create high-volume synthetic datasets that replicate real-world network conditions, including rare failure scenarios (e.g., "black swan" events). This capability allows the Twin to pre-train and validate AI/ML models in a safe virtual environment before deployment, significantly reducing the time and risk associated with training on live infrastructure.		
Dependency	Available physical network and other components in the Unity-6G architecture		

Traceability (Backward)	N/A
Traceability (Forward)	Apply predicted actions over the specific domain.
UNITY-6G components	• DT + Transport Components | Functional: MS, AE, DE and ACT
Linked KPIs	• KPI#6: Decrease service creation and termination time (PoC#2, ES#3). • KPI#26: Increase the ratio of service management and LCM tasks resolved by local AE/DE components • KPI#27: Reduction of 80% of training/inference time of AI/DRL-based algorithms (relying on AI assisted data generation)

ID	**Req-UC3-08**	**Priority**	**SHOULD**
Name	Real-Time Sustainability & Microgrid Interaction Monitoring		
Description/ Rationale	The DT must continuously monitor and visualize sustainability metrics, specifically the interplay between network energy demand and local microgrid status (e.g., renewable energy availability). It serves as the Sustainability Evaluator, so that operators may simulate and enact "what-if" scenarios that optimize load balancing based on carbon footprint and energy cost, ensuring eco-friendly operations.		
Dependency	Integration with smart grid/microgrid data interfaces and real-time power consumption telemetry from network nodes (O-RU, O-DU, Edge Servers).		
Traceability (Backward)	Sustainable, energy-efficient network deployments.		
Traceability (Forward)	DE for energy-aware routing and workload placement.		
UNITY-6G components	• DT Sustainability Dashboard, Energy Data API and Microgrid Interface, AE (Energy profiler) and O-RAN energy saving related rApps/xApps		
Linked KPIs	• KPI#28: An average accuracy of up to 90% in energy consumption estimation compared to physical testbed measurements. • KPI#33: Validation of energy-saving gains (target >15%) through DT-simulated microgrid interactions.		

ID	Req-UC3-09	Priority	SHOULD
Name	Cross-Domain SLA Verification		
Description/ Rationale	The DT must simulate the end-to-end network performance that span heterogeneous domains (e.g., terrestrial RAN, Transport, and Satellite/NTN). Before the network is provisioned in the live network, the DT must validate that the configuration will meet strict SLAs for latency and throughput, to prevent violations in complex, multi-vendor environments.		
Dependency	Access to topology data from all domains (TN/NTN) and performance models for inter-domain interfaces.		
Traceability (Backward)	Supports the goal of "Integrated 6G Network Evaluation" by ensuring disparate domains work together seamlessly.		
Traceability (Forward)	Enables ZSM and reliable service orchestration.		
UNITY-6G components	• E2E Service Manager • DT Network Topology • AE (SLA Prediction) • Cross-domain Orchestrator (IDMO)		
Linked KPIs	• KPI#6: Decrease service creation and termination time (target -30%). • KPI#26: Increase the ratio of service management tasks resolved automatically by AE/DE to >90%. • KPI#10: Guarantee cross-domain (cellular-IEEE 802.11) end-to-end latency smaller than 20 ms after reconfiguration. • KPI#11: Guarantee cross-domain jitter of max of 2 milliseconds, with less than 10% of packets that missed the deadline • KPI#12: Guarantee a prediction accuracy on end-to-end latency and jitter of 99.9%		

3.4.3 Use Case #3 KPIs

The KPIs associated with this use case are listed in the table below:

KPIs	Description	Scenario for main KPI	Objective	Measurement Methodology

#6	Decrease service creation and termination time (PoC#2, ES#3).	PoC KPI	N/A	**Definition:** • Service Creation Time: The total time elapsed from the initiation of a service instantiation request to the point when the service is fully operational and ready to handle traffic. This includes network instantiation, VNF deployment, configuration, and activation phases. • Service Termination Time: The total time required to gracefully decommission a service instance, including resource deallocation, state cleanup, and confirmation of complete service removal. • Target Metric: The reduction in service lifecycle management time achieved through AI-based automation, DT verification, and distributed management architecture. **Standards Used:** 3GPP network management specifications (TS 28.530, TS 28.541) and ETSI Zero-touch network and Service Management framework. The DT approach takes basis from ITU-T Y.3090 recommendations for network DT architecture. **Measurement Methodology:**

				1. Deploy the UNITY-6G integrated architecture with DT service for management and load balancing across multi-domain infrastructure (O-RAN, X-haul, Satellite). 2. Establish baseline measurements using traditional service orchestration without DT validation. 3. Initiate service creation requests with varying complexity levels (single domain vs. multi-domain). 4. Utilize the DT platform to pre-validate service configurations, predict resource requirements, and simulate deployment before physical instantiation. 5. Measure end-to-end time from service request to operational state, capturing intermediate phases (template processing, resource allocation, VNF instantiation, configuration). 6. For termination measurements, trigger service decommissioning and measure time until complete resource release and state cleanup.

				7. Apply AI-driven DEs and AEs within the distributed management architecture to optimize orchestration decisions. 8. Compare measurements with and without DT-assisted deployment to quantify improvement.
#9	Guarantee end-to-end latency (smaller than 20 ms)/reliability guarantees (99% of PDR) of time sensitive applications after reconfiguration.	PoC KPI	N/A	**Definition:** • E2E Latency: The total time taken for an application layer data packet to travel from the source application, through the entire network path to the destination application. • Reliability: The percentage of packets delivered within the 20ms latency bound. PDR is a core KPI, where PDR = 1 - PLR (Packet Loss Rate). **Standards Used**: The target values (<= 20ms Latency, 99% PDR) are similar to requirements for URLLC as defined by Standards Development Organizations (SDOs) such as ITU-R and 3GPP. **Measurement Methodology:** 9. Deploy a complete End-to-End network topology over single RAT (e.g., cellular only, Wi-Fi only, etc.).

				10. Initiate a continuous flow of traffic. 11. Introduce controlled environmental variations (e.g., varying traffic loads, channel conditions, etc.) when necessary. 12. Measure latency and packet delivery statistics. 13. KPI extraction.
#10	Guarantee cross-domain (cellular-IEEE 802.11) end-to-end latency smaller than 20 ms after reconfiguration.	PoC KPI	N/A	**Definition**: E2E Latency: The total time taken for an application layer data packet to travel from the source application to the destination application. **Standards Used:** The target values (<= 20ms Latency, 99% PDR) are similar to requirements for URLLC as defined by Standards Development Organizations (SDOs) such as ITU-R and 3GPP. **Measurement Methodology:** 1. Deploy a complete End-to-End network topology over multi-RAT (e.g., cellular + Wi-Fi). 2. Initiate a continuous flow of traffic with no reconfiguration. 3. Capture baseline E2E latency.

				4. Trigger the reconfiguration event. 5. Measure Latency after reconfiguration. 6. Introduce controlled environmental variations (e.g., varying traffic loads, channel conditions, etc.) 7. Repeat latency measurement. 8. KPI extraction.
#11	Guarantee cross-domain jitter of max of 2 milliseconds, with less than 10% of packets that missed the deadline	PoC KPI	N/A	**Definition:** • Jitter (Packet Delay Variation): The variation of End-to-End Latency. • Reliability: The percentage of packets delivered within the 2 ms delay jitter bound. **Standards Used**: The concept of Jitter is a standard performance metric used for real-time services and has been defined in IEEE TSN, IETF DetNet related standards. **Measurement Methodology:** 1. Deploy a complete End-to-End network topology over multi-RAT (e.g., cellular + Wi-Fi). 2. Initiate a continuous flow of traffic.

				3. Measure baseline jitter distribution. 4. Introduce controlled environmental variations (e.g., varying traffic loads, channel conditions, etc.) 5. Run the test for an extended, statistically representative period to capture all operational states. 6. Measure jitter distribution
#12	Guarantee a prediction accuracy on end-to-end latency and jitter of 99.9%.	PoC KPI	N/A	**Definition**: Prediction accuracy: The closeness of the AI/ML system's predicted value to the actual measured value that fall within an acceptable error margin for a given network metric (E2E Latency or Jitter) **Standards Used**: No. **Measurement Methodology:** 1. Deploy the full Multi-RAT physical network (e.g., cellular and Wi-Fi) with the AI/ML optimizer. 2. Ground-Truth Collection 3. Run controlled traffic experiments 4. Measure actual E2E latency and jitter for each packet 5. Prediction Collection 6. Activate the AI/ML optimizer

				7. Run controlled traffic experiments 8. Collect the E2E latency and jitter generated by the AI/ML model 9. Compare Prediction vs Ground Truth 10. Calculate the Absolute Percentage Error (APE) for each sample 11. Calculate the Mean Absolute Percentage Error (MAPE) over all N samples 12. Calculate the Prediction Accuracy
#13	Ensure a calibration delay smaller than one second (non-real-time applications).	PoC KPI	N/A	**Definition:** • **Calibration Delay:** The time elapsed between the collection of network state data (from the physical network) and the synchronization of the DT model to reflect this new state. • **Non-Real-Time Applications:** Applications that do not require immediate, sub-millisecond response times but still rely on accurate, up-to-date network representations for valid decision-making (e.g., network planning, periodic optimization, capacity forecasting).

				• **Target Metric:** A calibration delay of < 1 second ensures that the DT maintains a "near real-time" fidelity with the physical network, sufficient for non-real-time management decisions without introducing significant errors. **Standards Used:** DT Networks is outlined in ITU-T Y.3090, which defines a real-time interactive mapping between physical and virtual entities. The distinction for non-real-time applications is consistent with O-RAN Alliance classifications for Near-RT (10ms-1s) and Non-RT (>1s) loops, placing this calibration target at the boundary of Near-RT performance. **Methodology:** 1. Define **the Southbound Interface:** Deploy timestamped data collectors at the physical network elements (PNFs[3]/VNFs) and the DT ingress points to measure data propagation time. 2. Trigger **Controlled State Changes:** Introduce changes in the physical network (e.g., traffic load variation, link

[3] Physical Network Functions

				failure simulation) to initiate a synchronization event.
				3. Monitor Update Cycle: Track the lifecycle of the update within the DT environment:
				  1. Collection Time: Time to gather telemetry data via O-RAN O1 interfaces or similar telemetry streams.
				  2. Processing Time: Time for the AE to process raw data and update the DT's internal state model.
				  3. Synchronization Time: Time until the DT state is fully committed and available for query by Northbound applications.
				4. Calculate Total Delay: Compute Total Delay = T_available_in_DT - T_event_occurrence_in_Physical_Network.
				5. Verify that the measurements remains below 1.0 seconds for non-real-time application scenarios.

#26	Increase the ratio of service	PoC KPI	Obj#1	**Definition:** This KPI measures the proportion of service-management and LCM tasks that are fully resolved

	management and LCM tasks resolved by local AE/DE components.			by local AE and DE, without requiring escalation to centralized orchestration systems (e.g., 6G, Non-RT RIC, or cloud-hosted controllers). Service management tasks refer to actions related to monitoring, configuration, fault handling, performance optimization, and policy enforcement associated with RAN, transport, or NTN service instances. LCM (Lifecycle Management) tasks, refer to operations involved in deployment, scaling, update/upgrade, healing, and retirement of network functions or xApps/rApps/dApps. Local AE/DE components, refers to analytics and decision modules co-located with edge resources (e.g., Near-RT RIC, edge cloud, or domain-level controllers) and capable of executing decisions autonomously using DT inputs. A task is *“resolved locally”* when the AE/DE takes a corrective/optimization action that (i) does not require external approval or instruction from centralized entities, and (ii) leads to a stable and valid network state, verified through the DT or equivalent feedback loops. The KPI is expressed as a ratio of (number of service management + LCM tasks resolved locally) and total number of such tasks triggered. This

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				measures the degree of decentralization, autonomy, and DT-enabled self-management within the target domain. **Standards Used:** No definition of such KPI ratio is defined but the concepts of localized autonomy, AE/DE decision loops, and DT-driven execution, forms the basis for the KPI. **Measurement Methodology:** This KPI is evaluated by observing how many service-management and LCM tasks are autonomously completed at the local AE/DE level across the duration of tests, simulations, or deployments. *For trigger tasks*, a defined set of service-management and LCM tasks are triggered during controlled experiments or live operation (e.g., optimization events, fault alarms, scaling requirements). *During recording resolution path,* for each task, the system logs whether, it was resolved locally by AE/DE; or it required escalation to SMO / Non-RT RIC / cloud controller. *For DT verification*, the DT validates whether the local action results in a stable and acceptable state (e.g., performance within thresholds, no new conflicts introduced). *To compute ratio*, at the end of the observation window, the fraction of tasks resolved locally is computed using the definition. *To*

				compare against baseline, baseline values (e.g., manual or centralized operation) are compared to post-automation results to quantify improvement. An example simplified logical flow is: Run baseline test 1. Measure number of escalated tasks 2. Enable local AE/DE + DT 3. Run identical scenarios 4. Count tasks resolved locally 5. Compare ratios.
#27	Reduction of 80% of training/inference time of AI/DRL-based algorithms (relying on AI assisted data generation)	PoC KPI	Obj#4	**Definition:** This KPI measures the improvement in efficiency of AI and DRL models used for network control, comparing their training time and inference time with and without DT-enabled AI-assisted data generation. Training time is defined as the time required to train an AI/DRL model from initialization until it reaches a predefined performance threshold (e.g., convergence criteria, reward stability, accuracy target). During training, the DT can generate large amounts of synthetic data for learning or serve as a simulation environment for DRL, dramatically reducing the time required to reach usable performance (what might require

				several days of real PoC data collection can often be replicated in just a few hours). In the exploitation phase of DRL, the agent no longer needs to interact with the physical PoC setup, allowing exploration and refinement to proceed far more rapidly and without operational risk. Inference time is the execution time required for the trained model to produce an output (e.g., xApp control action, prediction, optimization decision). During inference, the DT enables "what-if" evaluations before actions are applied to the real network, while this can increase inference time for DRL, several strategies help mitigate delay, such as online or incremental learning and the use of cached scenario outcomes. Moreover, because DT simulations can replay a full window of packet-level features much faster than real time, they can deliver quicker responses than a physical network that must wait for actual traffic to arrive. AI-Assisted *data generation* is the process in which the DT produces synthetic, augmented, or accelerated datasets (e.g., simulated RAN states, transitions, rewards, or counterfactual data) to reduce the need for real-world data collection and to shorten the training cycle.

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				Reduction of 80% is UNITY-6G -level target indicating that the time required for model training and/or inference when using DT-generated data should be 80% lower than the time required using purely real data and conventional training pipelines. KPI target is satisfied if τ ≥ 0.80 where τ is (1 - $\frac{T_{DT-enabled}}{T_{baseline}}$). This KPI reflects the DT's ability to speed up AI lifecycle operations and increase responsiveness of intelligent control loops. **Standards Used:** Standards do not specify exact percentages for AI training-time reduction. The 80% reduction figure is not derived from a standard but is a UNITY-6G requirement, justified by the ambition to dramatically shorten AI lifecycle timelines for near-RT control. **Measurement Methodology:** The KPI is evaluated by comparing AI/DRL model training and inference times with a baseline (no DT assistance) versus a DT-enabled pipeline. To establish baseline (*no DT assistance),* train the AI/DRL model using only real data or conventional offline datasets and record training time and average inference time. To enable DT-based AI-assisted data generation, generate synthetic or

				augmented datasets using the DT (e.g., simulated transitions, mobility traces, channel conditions) and retrain the model using this accelerated or expanded dataset. To measure *DT-enabled training/inference times*, record the new training time and inference time. To compute reduction ratio, compare baseline vs. DT-enabled times using the defined formula. To check against the 80% target, KPI is achieved if the reduction ratio ≥ 0.80. A logical example flow is 1. Run training baseline 2. Enable DT data generation 3. Retrain 4. Compare training cycles 5. Extract percentage reduction
#28	An average accuracy of up to 90% in energy consumption and 80% in resource allocation compared to a testbed instance.	PoC KPI	Obj#4	**Definition:** This KPI measures the predictive fidelity of a DT by comparing its estimated outcomes with real-world results obtained from a reference testbed instance. It focuses on two core prediction domains: Energy consumption accuracy (up to 90%) *is* the percentage closeness of the energy usage predictions made by the DT (e.g., per service, per node,

				per orchestration decision) to the measured consumption in the physical testbed. Resource allocation accuracy (up to 80%) is the extent to which the NDT-predicted resource allocation states (CPU, memory, spectrum, etc.) match the actual allocation decisions observed in the testbed system under the same control inputs and environmental conditions. The term *“accuracy”* refers to how close is prediction to actual where the absolute error is averaged over a defined set of evaluation intervals or scenarios. This KPI demonstrates the modelling precision and synchronization fidelity of the DT and supports its use in safe what-if testing, closed-loop orchestration, and forecast-based planning without degrading trust or performance. **Standards Used:** There is currently no universal standard defining acceptable accuracy thresholds for DT predictions in networking. The thresholds (90% for energy and 80% for resource allocation) are quantitatively defined as UNITY-6G specific targets, ensuring the DT is actionable and not just observational. **Measurement Methodology:** *For testbed deployment,* deploy the target service(s) or orchestration

				scenarios in a controlled physical or emulated testbed, collect real measurements, energy consumed per component or task (e.g., via power meters or telemetry), actual resource allocation over time (e.g., CPU cycles, memory, scheduling logs). For DT execution (mirror simulation), simulate or emulate the same workloads in the DT instance, under identical service intents and environmental conditions. Use real-time or historical telemetry to drive the NDT's model state. For prediction comparison, at defined intervals or checkpoints, compare the DT predictions with the real testbed values for: energy consumption (e.g., total kWh, node-level usage), resource allocation (e.g., scheduling decisions, utilization levels) and compute accuracy for each domain. For evaluation and reporting, report the mean accuracy over all scenarios, separately for energy and resource metrics, include variance, failure cases, and sensitivity to data delays or noise, validate against the 90% (energy) and 80% (resource) thresholds.
#29	Generate accurate and reusable	PoC KPI	Obj#4	**Definition:** This KPI evaluates the ability of a GenAI model (e.g., GANs, diffusion models, foundation models

	GenAI enhanced data for DT.			fine-tuned for network data) to generate synthetic datasets that are both *accurate*, the generated data faithfully replicates the statistical and behavioral properties of real-world network telemetry, traffic patterns, resource usage, or system events as observed in testbed or live environments, *reusable*, the synthetic data can be reliably used across multiple DT modules (e.g., training predictors, simulating what-if scenarios, validating decision models) without retraining or re-generation, and maintains utility across time, use cases, or configurations. In this context, *GenAI-enhanced data* refers to data produced by trained AI models that can emulate realistic network dynamics or service behavior under varying contexts, *DT* refers to the virtual replica of the physical network, including its topological, functional, and operational models. The KPI aims to validate the fitness of generated data for simulation, training, or forecasting purposes within a DT, with respect to, statistical fidelity (e.g., distribution similarity), cross-domain applicability (e.g., works across slices, domains), temporal consistency (e.g., aligns with real-world trends) and functional usefulness (e.g., no performance

				drop when used in model training vs. real data). **Standards Used:** There are no current finalized standards specifically governing the use of GenAI data in DT systems. **Measurement Methodology:** *For training and generation phase,* a GenAI model is trained using real data collected from the physical network or testbed (e.g., telemetry, energy consumption, flow logs), the model generates synthetic datasets reflecting comparable conditions and configurations. For *accuracy assessment (fidelity testing),* compare the statistical properties of generated data with the original dataset using distribution similarity metrics (e.g., KL divergence, Wasserstein distance), temporal alignment tests (e.g., autocorrelation, seasonality), feature-wise deviation across key metrics (e.g., latency, throughput). Define minimum similarity thresholds (e.g., ≥90% match) for acceptance. For *reusability assessment (functional utility testing),* use the generated data in place of real data in one or more DT modules (e.g., AI model training, what-if simulation, anomaly detection), compare the output performance (e.g., prediction

				accuracy, decision quality) of these modules when trained or run with synthetic vs. real data, repeat across different configurations and time windows. For reporting, report, fidelity scores (e.g., average distance between distributions), reusability metrics (e.g., relative drop in model accuracy or DT decision quality), qualitative feedback (e.g., false positives/negatives introduced). KPI is met if both, accuracy exceeds defined thresholds (e.g., ≥90% for target metrics) and reusability does not degrade downstream module performance by more than some percentages (e.g., <5% relative loss).
#30	Decrease service creation and termination time (PoC#1, ES#3-Network Evaluator with GenAI data enhanced DT).	PoC KPI	Not available in objectives	**Definition:** This KPI measures the improvement in end-to-end service creation time and service termination time for a *Network Evaluator* function when its decision and validation processes are supported by a DT enhanced with GenAI-based data generation. Service creation time is the elapsed time from when a service instantiation request is triggered (e.g., slice creation, RAN configuration template instantiation, network function chain creation) until the service reaches an operational and validated state.

				Service termination time is the elapsed time between issuing a service removal/termination request and the complete deallocation of related resources (compute, radio, configuration state, policies). Network evaluator is a decision-support or validation component that assesses service feasibility, resource requirements, expected KPIs, SLA compliance, and configuration validity before creation or termination. In the UNITY-6G context, this evaluator integrated with the DT confirm correctness before actions are executed. Generative-AI-*enhanced DT* is a DT that uses GenAI models (e.g., diffusion models, generative simulators, surrogate models) to quickly produce realistic synthetic states, predicted performance metrics, and configuration impacts, reducing time spent on data collection, simulation setup, or slow physics-based modelling. Decrease in *time* is a UNITY-6G-defined improvement in which the DT with generative-AI acceleration results in a measurably lower service creation and termination time compared to a baseline workflow where the evaluator relies only on real-time data. This KPI is defined as

				$$KPI = \frac{T_{baseline} - T_{DT+GenAI}}{T_{baseline}}$$ A positive KPI value indicates improvement, UNITY-6G targets (e.g., % reduction) are justified by the need for faster zero-touch orchestration cycles in TN-NTN systems. **Standards Used:** No standard prescribes exact numerical improvements for service creation/termination time. The target reduction value itself is a UNITY-6G requirement, not from a standard. **Measurement Methodology:** The high-level evaluation methodology compares service creation and termination times with and without the generative-AI-enhanced DT. For baseline measurement (No DT or No GenAI), execute a sequence of service creation and service termination cycles. Record total time for decision loops. Compute average creation time and average termination time. For *Generative-AI-enhanced DT*, integrate DT-based prediction and validation into the evaluator and enable generative models to fast-produce synthetic network states, KPI estimates, or service-impact predictions.

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				For *running the same creation/termination tests*, repeat the service request cycles and record new creation and termination times. For computing *the reduction KPI*, compare baseline vs. DT-enhanced timings using the above defined formula. For e*valuating KPI achievement*, assess if reduction meets targets and validate results across multiple runs or scenarios (TN-NTN). A logical example flow is 1. Run baseline 2. Enable DT + GenAI 3. Repeat tests 4. Compare time reductions 5. Extract KPI value
#31	Reduce service recovery time below 180s.	PoC KPI	Obj#3	**Definition**: Service Recovery Time: The total duration measured from the moment a service failure (i.e., a major KPI violation) is detected until the moment the service is fully restored. **Standards Used**: Several standards provide definitions or expectations relevant to service continuity, failure recovery, and performance restoration: e.g., 3GPP TS 23.501 / TS 23.502. It is also one of the target KPI target in ICT-52 projects and have identified in 5GPPP [21].

				Measurement Methodology: 1. Baseline Service Setup a. Configure the full Multi-RAT network (Cellular and Wi-Fi). b. Establish a baseline traffic flow and verify stable E2E performance. c. Record baseline QoS (latency/jitter/PDR) 2. Trigger a controlled failure event that severely impacts the monitored KPI 3. Measurement of Recovery Time a. Detection Time: Record the time when the monitoring system first detects the KPI violation or component failure. b. Restoration Time: Record the moment when the E2E performance of the flow returns to the pre-defined minimum acceptable level. c. Calculate Individual Service Recovery Time.

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				4. KPI validation a. Repeat the failure simulation (Step 2 and 3) multiple times (N) under different conditions. b. Calculate the Mean Service Recovery Time (MTTR).
#41	Reduction of 70% of deployment time of AI-based resource/energy management algorithms.	Theory/Simulation/Emulation only	Obj#4	**Definition:** This KPI measures the improvement in the deployment time of AI-based resource and energy management algorithms when the deployment lifecycle is assisted by a DT. Deployment includes model selection, validation, packaging, onboarding, configuration, and activation within the target network domain (e.g., near-RT RIC, SMO, edge cloud). D*eployment time* is the total elapsed time from when an AI model (for resource allocation, energy optimization, load balancing, etc.) is ready for operationalization to the moment it becomes fully active and functional in the network. Deployment time includes model validation and safety checking, compatibility testing (e.g., with existing xApps/rApps), policy and constraint verification, packaging/onboarding into the

				execution environment, activation and final readiness confirmation. AI-Based *resource/energy management algorithms* are algorithms designed to optimize RAN or TN–NTN resources (e.g., PRB allocation, control, activation, sleep modes) using ML/DRL, supervised models, or generative model. DT is a virtual representation of the network that can evaluate model behavior, test configurations, and validate algorithmic decisions before deployment. In this KPI, the DT enables faster pre-deployment testing, automated compatibility checks, and reduced manual validation cycles. Reduction of 70% is UNITY-6G-defined improvement target indicating that the DT-assisted deployment pipeline should reduce the total deployment time to 30% of its baseline value (i.e., a 70% reduction). Formally, this KPI is defined as $$KPI = 1 - \frac{T_{DT-assisted}}{T_{baseline}}$$ and is met if KPI ≥ 0.70. **Standards Used:** No existing standard mandates a specific numerical target, but the 70% reduction target itself is a UNITY-6G requirement, justified by the need to

				accelerate AI-driven control loops and reduce operational complexity. **Measurement Methodology:** This KPI is evaluated by comparing baseline deployment time (without DT support) against deployment time when DT-assisted automation is enabled. For baseline measurement (*no DT)*, deploy a representative AI-based resource/energy management algorithm using conventional workflows and record total deployment time, including validation, testing, packaging, and activation. For DT-assisted deployment, use the DT to perform pre-deployment validation, conflict checking, resource estimation, and scenario-based testing and use automated DT-driven compatibility and constraint verification to reduce manual checks. To r*un the deployment process with DT*, record the total time required to deploy the same algorithm using DT assistance. To *compute deployment time reduction*, apply the KPI formula comparing baseline and DT-assisted times.

				To *evaluate KPI target achievement*, determine whether the reduction meets or exceeds the 70% target. A logical example flow is 1. Run baseline deployment 2. Enable DT validation 3. Deploy again with DT 4. Compare times 5. Extract reduction metric
#42	DT-validated AI algorithms that do not break the time-sensitive operation when deployed in 99% of the outputs.	Theory/Simulation/Emulation only	Obj#4	**Definition:** This KPI how the AI/ML models that are developed, trained and validated in a DT environment perform when deployed in the real environment in usual network operations. For instance, reinforcement learning algorithms that are trained on a trial-and-error basis, anomaly detection and predictive maintenance models, as well as automated service provisioning network optimization methods that have been designed and developed in the DT are deployed in the real environment and normal operations, without compromising the latency requirements in 99% of the cases. **Standards Used**: No existing standard is associated with this KPI. **Methodology:** Different AI/ML models will be trained in the DT (e.g., a reinforcement learning model for

				resource optimization and a forecasting model), will then be validated and deployed through model serving methods (e.g., TFserving, Kserve, etc.) as standalone models in real infrastructure (server). The online operation of these models will be then measured during the inference workflow in terms of accuracy and inference latency, quantifying the additional delay vs the baseline method, i.e., no AI/ML model is present and working in the online operation of the network.

3.4.4 Use Case #3 KVIs

We have defined a number of KVIs that are listed in the table below:

KV as criterion and goal	KV as outcome	Use case KVIs	Target
Environmental Sustainability	KV: Higher network energy efficiency and composition with greenness in favor Stakeholder: Network operators, society, industry, policymakers Effect on: *Activity, state of being*	Resources: Sustainability of the network through the composition of the used energy.	Reduced by a *percentage*
Economic Sustainability	KV: Proactive energy/resource	Process: Improper deployments where	Reduced by a percentage

	optimization in operations via DT simulation and calibration Stakeholder: Network operators, industry Effect on: Process, state of being	metrics are worse for the next iteration.	

3.4.5 Use case #3 Mapping Requirements to KPIs

KPI\ Requirement	#6	#9	#10	#11	#12	#13	#26	#27	#28	#29	#30	#31	#41	#42
Req-UC3-01									■					■
Req-UC3-02												■	■	
Req-UC3-03	■						■							
Req-UC3-04	■										■			
Req-UC3-05	■										■			
Req-UC3-06	■										■			
Req-UC3-07	■						■	■						
Req-UC3-08										■				
Req-UC3-09	■	■	■	■	■	■								

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3.5 USE CASE #4 - MULTI-RAT O-RAN ENABLED NPN FOR SUPPORTING TIME SENSITIVE APPLICATIONS FOR INDUSTRY 4.0

3.5.1 Use Case Description

Reliable and deterministic communications are fundamental for enhancing of industrial automation processes at the factory floor. Many of Industry 4.0 applications require deterministic, low latency and high reliability communication networks, which currently are supported by wired Time Sensitive Networking (TSN). However, relying solely on wired-based infrastructure limits mobility support and flexibility, two requirements that are highly essential for industrial operations.

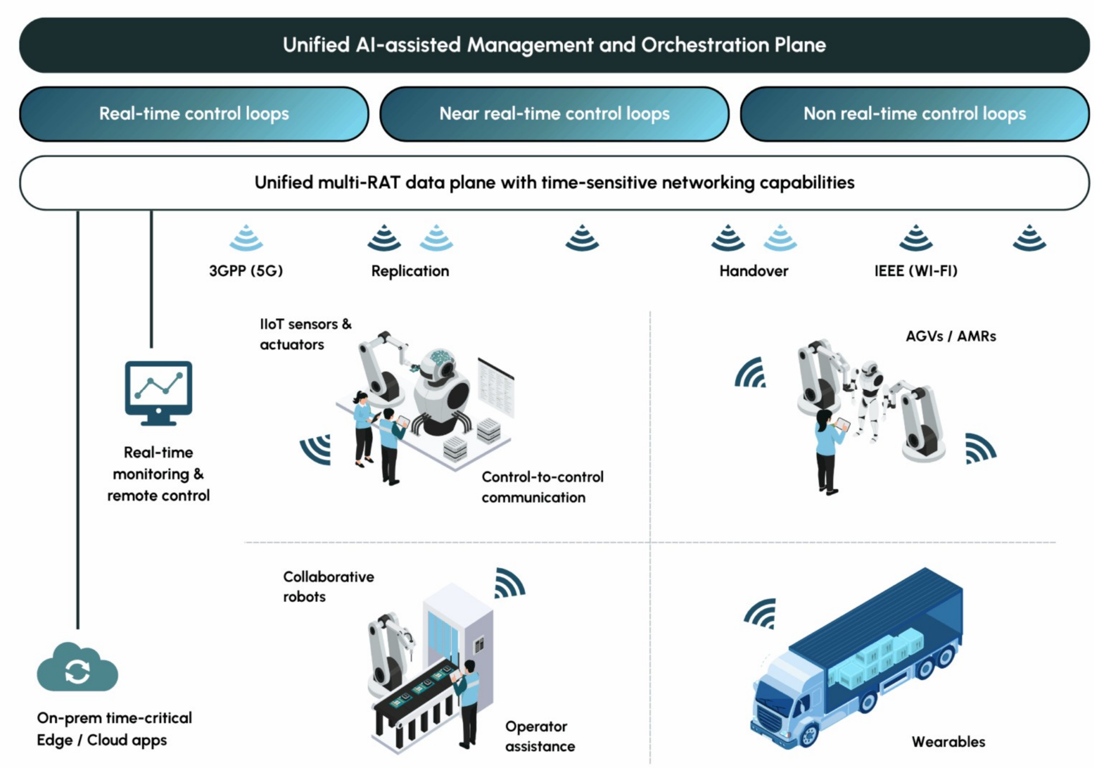

Figure 3-6 Use Case #4: Multi-RAT O-RAN enabled NPN for supporting time sensitive applications for Industry 4.0

In this use case, as shown in Figure 3-6, we explore the possibility of UNITY-6G architecture to support multi-RAT, integrating cellular RAN with IEEE 802.11, for the purpose of realizing O-RAN enabled NPNs in industrial settings.

The deployment of 6G NPNs addresses specific needs tailored to specific use cases, such as deterministic communication for industrial automation in an Industry 4.0 scenario. By incorporating multi-RATs within 6G RAN, NPN deployments aim to deal with increased application diversity with demanding requirements in terms of deterministic low latency and high reliability. Establishing a unified method to manage and control multi-technologies within 6G RAN will enable seamless and end-to-end network optimization to support demanding industrial automation applications. This can be done by exploiting the O-RAN framework from the cellular domain that is already standardized for 5G technologies, while 6G standardization activities are ongoing. Utilizing an O-RAN-based architecture to manage and control IEEE 802.11 network domain will enable unified management and control plane for both (cellular and IEEE 802.11) domains. By leveraging the O-RAN framework architecture private network operators can cross-optimize both radio access technologies (cellular and IEEE 802.11) with the aim of supporting end-to-end time sensitive communication. In addition, O-RAN-enabled IEEE 802.11 APs can be managed directly by dApps (real-time)/xApps (near real-time)/rApps (non-real-time) running on top of respective unified RICs.

Several scenarios can be covered in this use case, including wireless robotic systems, collaborative robot scenarios, and closed-loop control systems. Wireless robotic systems require both wireless connectivity for mobility support and deterministic communication for control precision. Each robot consists of several sensors (e.g., position, rotation, and force sensors), a motion controller, and several actuators (e.g., linear actuators and servo drive). All these sensors and actuators need to be connected to a backend system which hosts motion controller capabilities.

In a collaborative robot scenario, multiple robots cooperatively perform complex tasks requiring data exchange, coordination, and safety control to avoid collisions within themselves and with human workers. These robots utilize local networking via a base station or device-to-device ad hoc communication to exchange sensor data or emergency stop messages. Deterministic communication ensures safe and synchronized operations, even with mobility and interference dynamics.

In a closed-loop control system scenario several sensors perform measurements and inform the controller for the monitored environment. The control takes the decision and informs the actuators to perform certain actions. In certain cases, such communication needs to be wireless to support flexibility and mobility.

All the above-mentioned scenarios require reliable, deterministic, and low-latency communication over wireless, while maintaining connectivity over the factory floor. This use case will demonstrate how multi-RAT O-RAN enabled NPNs will maintain time-sensitive application requirements for industrial devices under various challenging conditions: i) increased network load on one of the RATs; ii) coverage degradation or shadowing; iii) device mobility across RAT coverage zones. Through control apps deployed in RIC, the network dynamically adapts time-sensitive flows as well as RAT configurations using available controlling knobs and monitored data. The UNITY-6G architecture will validate how multi-RAT NPNs will sustain end-to-end deterministic performance in heterogeneous wireless environments, paving the way for flexible, reliable and time-aware industrial automation networks.

3.5.2 Use Case #4 Requirements

For this use case we have specified several system requirements that are linked to KPIs in section 3.5.3. The description, their dependency and relation to KPIs are listed in the table below.

ID	**Req-UC4-01**	**Priority**	**MUST**
Name	Scheduling in Wi-Fi segment		
Description/ Rationale	Multi-RAT NPN system must support scheduling possibility by allocating dedicated time slots to specific traffic flows and nodes in the Wi-Fi segment		
Dependency	Depends on Req-UC4-02		
Traceability (Forward)	This requirement will be covered in WP3, T3.1 and demonstrated in PoC#1-ES #1 and ES #2		
UNITY-6G components	• O-RAN enabled AP • W-TSN (Wireless TSN) stations		
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.		

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ID	Req-UC4-02	Priority	MUST
Name	Time synchronization in Wi-Fi segment		
Description/ Rationale	Multi-RAT NPN system must support time synchronization mechanism for Wi-Fi segment		
Dependency	NA		
Traceability (Forward)	This requirement will be covered in WP3, T3.1 and demonstrated in PoC#1-ES #1 and ES #2		
UNITY-6G components	• O-RAN enabled AP • W-TSN stations		
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.		

ID	Req-UC4-03	Priority	MUST
Name	End-to-end time synchronization across different domains		
Description/ Rationale	Multi-RAT NPN system must support end-to-end time synchronization across different domains (RAN, core, Wi-Fi) for the purpose of monitoring and accurate scheduling		
Dependency	Req-UC4-02		
Traceability (Forward)	This requirement will be covered in WP3, T3.4 and demonstrated in PoC#1-ES #1 and ES #2		

UNITY-6G components	• O-RAN enabled AP • W-TSN stations • Transport • O-RAN • Core
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	Req-UC4-04	Priority	SHOULD
Name	Low-level monitoring at network nodes		
Description/ Rationale	Multi-RAT NPN system should support low-level monitoring of different statistics regarding QoS for certain traffic flow as well as quality of channel and share that information with the controllers.		
Dependency	NA		
Traceability (Forward)	This requirement will be covered in WP3, T3.2 and demonstrated in PoC#1-ES #1 and ES #2		
UNITY-6G components	• O-RAN enabled AP		

	• W-TSN stations • Transport • O-RAN • Core
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	**Req-UC4-05**	**Priority**	**SHOULD**
Name	Monitored data processing		
Description/ Rationale	Multi-RAT NPN system should support monitored data processing locally as well as in their controller nodes		
Dependency	Req-UC4-04		
Traceability (Forward)	This requirement will be covered in WP3, T3.2 and T3.4 and demonstrated in PoC#1-ES #1 and ES #2		
UNITY-6G components	• O-RAN enabled AP • W-TSN stations • CNC (Centralized Network Controller)		

	• SMO
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	**Req-UC4-06**	**Priority**	**SHOULD**
Name	Exposing controlling knobs at network nodes		
Description/ Rationale	Multi-RAT NPN system should support exposing certain level of controlling knobs for controlling traffic classification/scheduling/steering in the multi-domain network		
Dependency	Req-UC4-05, Req-UC4-04		
Traceability (Forward)	This requirement will be covered in WP3, T3.2 and demonstrated in PoC#1-ES #1 and ES #2		
UNITY-6G components	• O-RAN enabled AP • W-TSN station • CNC • SMO		

Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	**Req-UC4-07**	**Priority**	**MUST**
Name	Distributed and collaborative AI/ML-assisted algorithms		
Description/ Rationale	The UNITY-6G intelligence layer must support distributed learning mechanisms for optimizing low-level radio resources (e.g., spectrum utilization, transmit power) of the O-RUs and Wi-Fi RUs. Moreover, collaborative learning methods like federated learning and transfer learning of locally trained ML models must be supported amongst the relevant network nodes.		
Dependency	Req-UC4-04, Req-UC4-05		
Traceability (Forward)	This requirement will be covered in WP4 (T4.1 and T4.2) and demonstrated in PoC#2-ES #2		
UNITY-6G components	• AI/ML Management Subsystem in the Intelligence Sublayer • Wi-Fi RUs and O-Rus • Near-RT RIC (global or locals)		

Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision • KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	**Req-UC4-08**	**Priority**	**SHOULD**
Name	Open RAN real time intelligence control loop		
Description/ Rationale	The intelligent applications residing in the RAN as dApps (either in the DU/CU or in the Wi-Fi APs) shall comply with the time scales of real-time intelligence control loop (< 10 ms).		
Dependency	Req-UC4-04, Req-UC4-05		
Traceability (Forward)	This requirement will be covered in WP4 (T4.2) and demonstrated in PoC#2-ES #2		
UNITY-6G components	• AI/ML Management Subsystem in the Intelligence Sublayer • dApps in the O-DUs/Wi-Fi APs		
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI#4: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision • KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision		

	• KPI#7: Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms. • KPI#8: Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline. Cross-domain jitter of max of 2 milliseconds, with less than 10% of the packets missing deadline.

ID	**Req-UC4-09**	**Priority**	**SHOULD**
Name	Advanced Wi-Fi techniques (e.g. multi-link) for low latency/TSN communications		
Description/ Rationale	The Wi-Fi network must support the Wi-Fi 7 Multi-link Operations (MLO). Additionally, it should support an innovative method that leverages MLO to achieve continuous and contention-free channel access in the unlicensed, thus reducing latency.		
Dependency	Req-UC4-01, Req-UC4-02		
Traceability (Forward)	This requirement will be covered in WP3, T3.1 and demonstrated in PoC#2-ES #1		
UNITY-6G components	• O-RAN enabled Aps • W-TSN stations		
Linked KPIs	• KPI#3: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution.		

ID	**Req-UC4-10**	**Priority**	**SHOULD**
Name	Dynamic service orchestration		
Description/ Rationale	Cloud-native applications including dApps/rApps/xApps should support orchestration procedures (such as resource scaling, intelligence triggered relocations and on demand instantiation) to dynamically adapt to their real-time resource and QoS requirements.		
Dependency	Req-UC4-06, Req-UC4-05, Req-UC4-04		

Traceability (Forward)	This requirement will be covered in WP3, T3.1 and T3.2, in WP5, T5.4, and demonstrated in PoC#2-ES #2
UNITY-6G components	• AE, DE, MS • Service Orchestration platform • Cloud-native infrastructure
Linked KPIs	• KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision

ID	**Req-UC4-11**	**Priority**	**MUST**
Name	Support TSN in xHaul		
Description/ Rationale	The xHaul network must support TSN requirements such as restricted and mandatory delay and jitter.		
Dependency	Req-UC4-03		
Traceability (Forward)	This requirement will be covered in WP3 and demonstrated in PoC#2-ES #1		
UNITY-6G components	• Wireless xHaul		
Linked KPIs	• KPI#2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context.		

ID	**Req-UC4-12**	**Priority**	**MUST**
Name	Support TSN service management		
Description/ Rationale	The xHaul network must support TSN service management including service admission control, service up and down.		
Dependency	NA		
Traceability (Forward)	This requirement will be covered in WP5 and demonstrated in PoC#2-ES #1		

UNITY-6G components	• Wireless xHaul
Linked KPIs	• KPI #5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision

ID	**Req-UC4-13**	**Priority**	**MUST**
Name	Support TSN service monitoring		
Description/ Rationale	The xHaul network must support TSN service detailed monitoring, such as per service packet loss, packet delay...		
Dependency	NA		
Traceability (Forward)	This requirement will be covered in WP3/5 and demonstrated in PoC#2-ES #1		
UNITY-6G components	• Wireless xHaul		
Linked KPIs	• KPI #2: Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context. • KPI #5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision		

ID	**Req-UC4-14**	**Priority**	**SHOULD**
Name	NEF-Based Exposure of UE/Asset Location and Mobility for Industrial NPN		
Description/ Rationale	NEF Location/Monitoring Event APIs should expose the position and mobility of key industrial assets to UC4 controllers and analytics so that mobility-aware scheduling, handover planning and RAT selection can be evaluated and, where needed, enforced for time-sensitive applications.		
Dependency	Requires a 5G SA core with NEF integrated to AMF implementation of Location/Monitoring Event APIs (TS 29.122/29.522), with secure exposure to UC4 AFs/controllers (RIC apps, NPN management) via CAPIF/OpenCAPIF or equivalent.		

Traceability (Forward)	Enables mobility-aware resource allocation, RAT selection and handover optimisation for industrial flows, and provides location traces that can feed TSN planning and DT components.
UNITY-6G components	• NEF Location exposure (5GC) • O-RAN RIC xApps/rApps/dApps • NPN/TSN controller • UC4 AE/DE and DT elements • CAPIF/OpenCAPIF, SBA/service bus
Linked KPIs	• KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision

ID	**Req-UC4-15**	**Priority**	**SHOULD**
Name	NEF-Based Exposure of QoS Monitoring and Influence for Time-Sensitive Industrial Flows		
Description/ Rationale	NEF QoS monitoring and traffic-influence APIs shall expose per-flow QoS status and allow authorised AFs (e.g., TSN controller, RIC apps, NPN manager) to request QoS adaptations so that UC4 can maintain bounded latency, jitter and loss for TSN-class flows across the 5G NPN and multi-RAT data plane.		
Dependency	Requires NEF support for QoS monitoring and traffic influence as specified in TS 29.522, integration with PCF/SMF/UPF configured for TSN/URLLC QoS profiles, and secure exposure to industrial AFs via CAPIF/OpenCAPIF or equivalent, including policies defining which AFs can influence QoS.		
Traceability (Forward)	Enables closed-loop QoS control for TSN and other critical flows, supports proactive SLA protection and allows AI/ML-based optimisation of multi-RAT resources under strict timing constraints.		
UNITY-6G components	• NEF Location exposure (5GC) • O-RAN RIC xApps/rApps/dApps • NPN/TSN controller • UC4 AE/DE and DT elements • CAPIF/OpenCAPIF, SBA/service bus		

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Linked KPIs	• KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision

ID	**Req-UC4-16**	**Priority**	**SHOULD**
Name	CAPIF Core Function Exposure of Service Discovery, Publication, Invoker Management, Logging and Auditing APIs for Time-Sensitive industrial flows and NPN networks supporting		
Description/ Rationale	OpenCAPIF shall provide discovery, publication, provider/invoker management and invocation logging for UC4 exposure APIs (at least NEF QoS, optionally Location and additional RAN/TSN metrics), enabling industrial controllers, RIC apps and monitoring tools to securely discover and consume network capabilities in a standardised way.		
Dependency	Requires deployment of CAPIF Core/OpenCAPIF implementing Discover_Service_API, Publish_Service_API, API_Invoker_Management, API_Provider_Management, Logging_API_Invocation_API and Auditing_API (TS 23.222), registration of UC4 NEF QoS (and other) APIs as providers with OpenAPI specs, onboarding of UC4 AFs (TSN controller, RIC apps, NPN manager, DT) as API Invokers, and integration with SBA/service bus and security framework.		
Traceability (Forward)	Enables scalable onboarding of industrial applications, centralised control of who can access which exposure capabilities, and collection of invocation logs useful for SLA verification and troubleshooting in UC4.		
UNITY-6G components	• NEF Location exposure (5GC) • O-RAN RIC xApps/rApps/dApps • NPN/TSN controller • UC4 AE/DE and DT elements • CAPIF/OpenCAPIF, SBA/service bus		
Linked KPIs	• KPI#5: Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision		

3.5.3 Use Case #4 KPIs

The KPIs associated with this use case are listed in the table below:

KPIs	Description	Scenario for main KPI	Objective	Measurement Methodology
#2	Maintain end-to-end latency (smaller than 20 ms) and reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context.	E2E latency measurement test between the TSN client and the server for data plane - separately for Wi-Fi and cellular. Measure also PDR. Measure KPI under dApp/xApp-assisted scenario in ES2 and compare it with ES1.	Obj#5	**Definition**: This KPI measures the time elapsed from the moment the packet is generated at the end device until the packet is received at the TSN server in the backend. This measurement will be performed separately for Wi-Fi and for 6G RAN. The reliability of the traffic flow accounts for the number of successfully and on-time received packets divided by the total number of transmitted packets. **Standard Used:** No standards are used for this KPI. **Measurement Methodology**: The KPI will be measured between the TSN end device connected via Wi-Fi as well as 6G RAN towards the TSN server running in the backend.
#3	An IEEE 802.11 traffic profile must ensure below 10 ms point-to-point latency in radio part only for the 99-th percentile of the delay distribution.	Measure the latency between the radio components – from Wi-Fi end device to Wi-Fi AP. Measure KPI under dApp/xApp-assisted scenario in	Obj#5	**Definition:** This latency in this KPI is defined as time elapsed from the moment the packet is transmitted from the end-device in Wi-Fi link until it is received at the Wi-Fi AP. **Standard used:** No standards are used for this KPI. **Measurement Methodology**: To measure this KPI we will send data from Wi-Fi station to Wi-Fi AP over a fixed period under different link load condition (e.g. 25%, 50% or 75% link capacity used) and

		ES2 and compare it with ES1		measure the latency. Then the 99-th percentile of the latency over measured time is calculated
#4	Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision	Decision from xApp/dApp and Actor of decision on the IEEE 802.11 AP	Obj#2	**Definition:** this KPI quantifies the required time to reconfigure the IEEE 802.11 network when a decision is taken from an intelligent application (ML-assisted) residing either in the Near-RT RIC (xApp) or the O-RAN-enabled WiFi Access Point (dApp). A decision recommended by the ML model could be for instance to adjust the power level of the WiFi AP. We therefore quantify the time between the post of the recommendation by the ML model and the actual implementation of the suggested action (the power of the WiFi AP is increased/decreased). **Standards Used:** No standards are used for this KPI. The real-time configuration requirement of "less than 10 ms" is aligned with the O-RAN AI/ML workflow and specifically with the intelligent control loop 1 for dApps. **Measurement Methodology:** Measure the latency from dApp/xApp output (WiFi AP/Near-RT RIC) to the actor that configures the recommendation (WiFi AP). No baseline comparison is needed for this KPI.

#5	Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision	Decision from xApp/dApp and Actor of decision on the O-RU	Obj#2	**Definition:** same as KPI#4, but the reconfiguration refers to the cellular network when a decision is taken from an xApp residing in the Near-RT RIC or a dApp hosted in the O-RAN DU. As an example, a decision recommended by the ML model could be the regulation of the power level of the RU. **Standards Used:** The real-time configuration requirement of "less than 10 ms" originates from the O-RAN AI/ML workflow and specifically from the intelligent control loop 1 for dApps (< 10 ms real-time control loop). **Measurement Methodology:** Measure the latency from dApp/xApp output (O-DU/Near-RT RIC) to the actor that configures the recommendation (O-RU or multi-RAT end device). No baseline comparison is needed for this KPI.
#7	Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms.	Measure latency from TSN client to the core (either through CU, UPF or through TSN switch). Due to the TSN features, but also due to	Obj#5	**Definition**: In this KPI cross-domain refer to a data path that is traversing at least once over a Wi-Fi link and over a 6G RAN link. End-to-end latency refers to time elapsed from the moment packet is transmitted in one end-node until it is received on the other end-device or node connected to the backend. **Standards used:** There are no standards used for this KPI.

		the tuples that are included in the O-RAN enabled Wi-Fi. Measure KPI under dApp/xApp-assisted scenario in ES2 and compare it with ES1		**Measurement Methodology**: This KPI will be measured by transmitting data traffic from an end-device that is connected to Wi-Fi to another device that is connected to 6G-RAN network to measure the latency over a path that crosses both domains.
#8	Cross-domain jitter of max of 2 ms, with less than 10% of the packets missing deadline.	Measure the jitter from client to the core (either through CU, UPF or through TSN switch) and the ratio of delayed packets. Due to the TSN features, but also due to the tuples that are included in the O-RAN enabled Wi-Fi. Measure dApp/xApp-assisted in ES2 and	Obj#5	**Definition**: Cross-domain here refers to the same concept as in KPI 7. Jitter refers to differences of experienced latencies of consecutive packets. **Standard used**: No standards are used for this KPI. **Measurement Methodology**: For this KPI we will follow the same methodology as in KPI 7. Here we will calculate jitter from the measured latencies. Moreover, we will calculate the percentage of packets that exceed the target of 2 ms.

		compare it with ES1		

3.5.4 Use Case #4 KVIs

We have defined a number of KVIs that are listed in the table below:

KV as criterion and goal	KV as outcome	Use case KVIs	Target
Production time	KV: Improved time-to-market for products. Stakeholder: Production sites, industrial sites. Effect on: Production process.		Reduced energy consumption per process unit.
Safer work environment	KV: Improve safety for workers, Improve number of medical leaves for the company. Stakeholder: Production site operator. Effect on: Workers		Reduced number of accidents at work due to communication failure.

KVIs in Use Case #4 can be evaluated using both model-based and real-world approaches. Simulations based on suitable models can provide an assessment of communication latency. In parallel, a twinned (DT) system can be used to evaluate system downtime. Finally, the actual system can be employed for KVI evaluation during PoC2.

3.5.5 Use Case #4 Mapping Requirements to KPIs

KPI\ Requirement	#2	#3	#4	#5	#7	#8
Req-UC4-01						
Req-UC4-02						
Req-UC4-03						

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Req-UC4-04						
Req-UC4-05						
Req-UC4-06						
Req-UC4-07						
Req-UC4-08						
Req-UC4-09						
Req-UC4-10						
Req-UC4-11						
Req-UC4-12						
Req-UC4-13						
Req-UC4-14						
Req-UC4-15						
Req-UC4-16						

3.6 COMMON KPIS WITHIN ALL UNITY-6G USE CASES

In addition to above KPIs for each use case, there are *common KPIs* for all requirements which are going to be investigated within all use cases.

- **KPI#1**: Deliver four distributed management entities (MS, AE, DE and ACT) deployable in each heterogeneous domain.
- **KPI #32**: Deliver two proof-of-concepts of the architecture: (i) TN – NTN and (ii) a time-sensitive NPN integrating both 3GPP and IEEE 802.11 technology.
- **KPI#39**: Design at least 5 APIs to expose network information including Open-source projects.
- **KPI#46**: Availability of four open-source frameworks and their corresponding API specifications for the UNITY-6G PoCs.
- **KPI#47**: Comprehensive documentation covering all aspects of the PoCs, including technical details, integration guides, and user manuals.
- **KPI#48**: Active participation and collaboration in the different SNS-JU boards, to coordinate efforts with other projects implementing testbeds and PoCs.
- **KPI#49**: Establishment of a support system to assist with the integration and use of PoCs in future projects.
- **KPI#50**: Documentation of harmonization and coordination efforts with other 6G initiatives.
- **KPI#51**: Liaison with at least 2 ongoing SNS stream C/D projects, exploring the potential integration of UNITY-6G solutions into their experimentation frameworks.
- **KPI#52**: Open-access datasets following format recommendations from the SNS-JU Testing, Measurement and Validation Working Group.
- **KPI#53**: Feedback reports from stakeholders and potential users, confirming the relevance and applicability of the PoCs

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4 PROOF OF CONCEPTS AND INTEGRATION OF THE UNITY-6G USE CASES

UNITY-6G will validate KPIs through at least one of its two main PoC setups developed within the project. The first setup, hosted at CTTC, will serve as a common platform for all network-related demonstrations. The second setup, located at IMEC, will focus specifically on TSN demonstrations. In total, UNITY-6G will implement six ESs across these two PoCs, three scenarios per setup, to showcase the targeted use cases and KPIs.
Refer to Table 3 for details on UNITY-6G objectives.

4.1 POC#1-ES#1: NETWORK RESOURCE SHARING AND SUSTAINABILITY

In this PoC, UNITY-6G deploys an integrated network combining terrestrial and NTN segments that share network resources and capacity as shown in Figure 4-1. The scenario represents a disaster situation where communication resources are scarce. Multiple tenants operate within this unified network, including MNOs providing cellular services, internet service providers (ISPs) offering broadband services, and satellite operators ensuring emergency communication services. To guarantee fair and transparent access to shared resources, trustworthiness and policies for conflict resolution have also been added to the network. Each tenant defines a set of policies that specify their requirements for energy consumption and network capacity. Each tenant could also have contradictory requirements. To ensure that these policies are followed, UNITY-6G will use distributed AI techniques, conflict resolution methods, including policy-based DEs, technologies such as DLT, XAI, These solutions enable continuous monitoring of resource usage, detection of policy violations, and efficient conflict resolution, ultimately creating a more sustainable and optimized shared-resource network that benefits all stakeholders.

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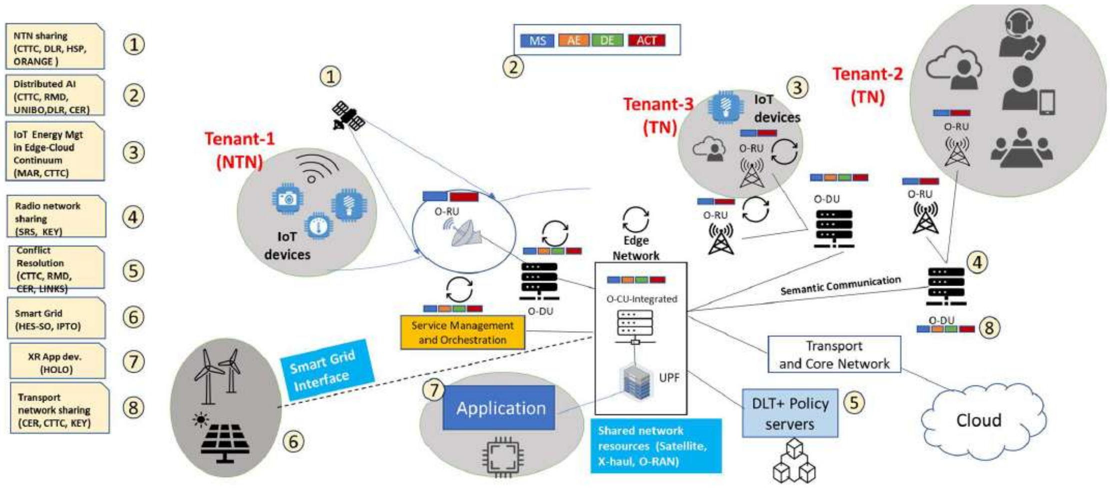

Figure 4-1 POC#1-ES#1 Network Resource Sharing and Sustainability.

Awareness of renewable energy production will be integrated into the network, and policies will be developed to encourage the use of renewable energy over non-renewable sources. For example, tenants could be incentivized to use energy during periods when renewable sources are most abundant, or when energy demand is low. Policies could also be developed to ensure that tenants are using energy efficiently, and that they are not wasting resources unnecessarily. Furthermore, ES#1 could also leverage a UNITY-6G network exposure layer, where standardized APIs provide abstracted views of RAN, transport and core status, as well as per-tenant resource usage. Through such APIs, the PoC controller can in principle query real-time metrics (e.g. flow-level QoS, link utilization, energy consumption) and trigger reconfiguration actions, without directly binding to vendor-specific management interfaces.

To implement this scenario, UNITY-6G will develop the necessary distributed AI algorithms for monitoring and conflict resolution, as well as policies for network resource sharing and allocation among multiple tenants in a dynamic manner. Standardized data models and protocols for sharing network usage information among the different tenants and the network itself will also be developed. IoT energy management techniques will also be integrated into the considered architecture. Finally, the integrated network infrastructure will be deployed and tested in a PoC setting to validate its effectiveness.

PoC#1-ES#1 related objectives: Obj#1, Obj#2, Obj#3, Obj#6 and Obj#7

Relevant KPIs of PoC#1-ES#1:

- **KPI#14**: Increase up to 20% usage of electricity from renewable sources thanks to close cooperation with local microgrid operation.
- **KPI#5:** Save up to 25% of energy costs by reducing CNF energy consumption.

- **KPI#16:** Reduce radio link power consumption up to 30% per link on average across a transport path (X-haul) due to full network coordinated load balancing, improved link utilization and distributed AI algorithms (between components O-RU, O-DU, O-CU links in Open RAN).
- **KPI#17:** Reduce CAPEX and OPEX with shared resources.
- **KPI#18:** Reduction in the deployment time of heterogeneous domain services.

4.2 POC#1-ES#2: 6G INTEGRATED NETWORK ORCHESTRATOR

In this PoC, a semantic-aware integrated network management system will be implemented using UNITY-6G's AI-driven 6G Orchestrator, as shown in Figure 4-2. The core component, the Semantic-Aware Analytics Engine (SA-AE) will be designed as a type of containerized software that uses advanced techniques to transmit summarized data, rather than simply transmitting it as raw information. By understanding the semantics or meaning of the data to be transmitted, the engine can identify patterns, relationships, and insights that might not be apparent through other means. In addition, ES#2 orchestration logic can be designed to interact with the underlying integrated network via open network-exposure APIs, offering a uniform interface to service-level information and configuration knobs across RAN, transport and core domains.

The SA-AE will also be integrated with other distributed functionalities (MS, AE, DE and ACT) to create a closed loop and improve accuracy and efficiency.

This architecture will optimize resource allocation across multiple UNITY-6G domains, including:

- Bandwidth allocation in NTN
- Compute resource allocation at the application layer (e.g., 3D information detection)
- Transport and radio network scaling in terrestrial domains.

The joint resource allocator component of the 6G orchestrator and system utilizes AI algorithms to intelligently allocate resources based on semantic context and user preferences.

Specific components include:

- Bandwidth allocator for satellite networks, prioritizing resources according to user demands using advanced AI techniques such as DRL.

- Application-domain resource allocator, assigning computing resources to tasks based on criticality and importance.
- Radio and transport scaling component, optimizing terrestrial network resources according to application requirements and network context.

Through this scenario, UNITY-6G will demonstrate that the semantic-aware integrated network management system with AI-driven 6G Orchestrator can significantly improve resource utilization and QoS, leading to a more efficient and sustainable network infrastructure.

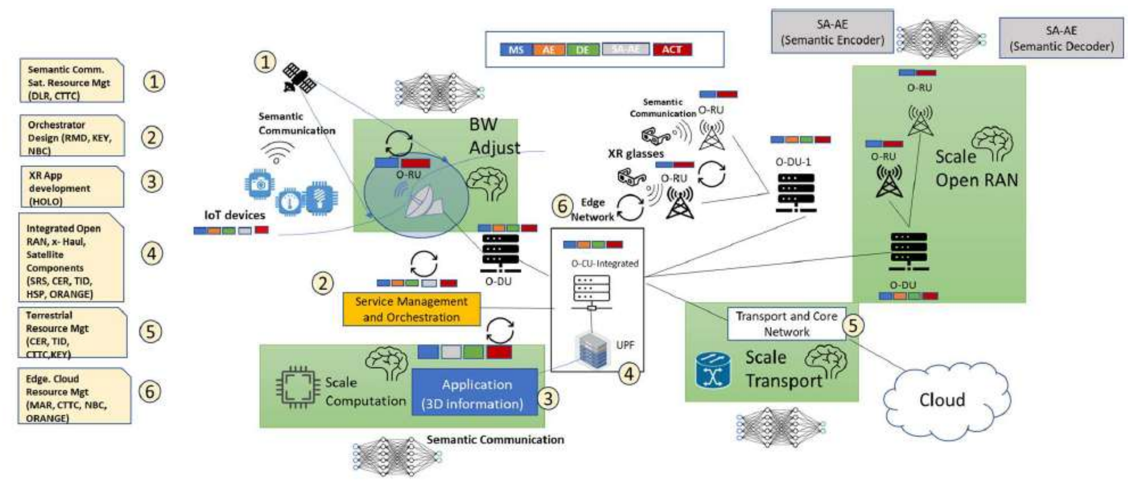

Figure 4-2 PoC#1-ES#2 6G integrated network orchestrator.

PoC#1-ES#2 related objectives: Obj#1, Obj#2 and Obj#5

Relevant KPIs of PoC#1-ES#2:

- **KPI#19:** Reduce time to manage network resources and management overhead and the reaction time by taking proactive actions in the network (time from identification to resolution via appropriate reconfigurations) with integrated design.
- **KPI#20:** Increase link utilization from 40% to 80%.
- **KPI#21:** Reduce the performance penalty due to conflicts by 20% by means of DLT, hierarchical AI algorithm and policy-based conflict resolution schemes Allocate 20% more network service LCM tasks.
- **KPI#23:** Reduction of communications overhead by a factor of 10 while maintaining the SLA requirements.
- **KPI#7:** Increase end-to-end message delivery latency, maximum message publish throughput in SBA service bus in integrated network scenarios.
- **KPI#25**: Increase service availability and reliability.

4.3 POC#1-ES#3: NETWORK EVALUATOR WITH GENAI DATA ENHANCED DT

In this PoC we will demonstrate 6G-Powered DT for integrated (open RAN, X-haul and satellite) network infrastructure monitoring as shown in Figure 4-3 This scenario aims to leverage the capabilities of 6G networks to develop a DT for the entire network infrastructure. DT will model physical assets such as network components and equipment, to facilitate network management and maintenance. The DT application will be AI-powered for observing the sustainability metrics of the whole network. The DT uses AI algorithms to monitor the sustainability metrics of the network, such as power consumption, and resource utilization, and to evaluate the effects of the interplay between microgrid power management and network operations. The DT will be integrated with open RAN, X-haul, and satellite technologies to enable real-time monitoring and management of the network infrastructure. The use of DT technology will provide network operators with a virtual representation of the physical network, allowing them to identify potential issues and make proactive decisions to optimize the network's performance and sustainability. In this direction, DT may be continuously synchronized with the physical network by consuming telemetry exposed through UNITY-6G network-exposure APIs, including traffic, performance and energy-related metrics. By leveraging the power of 6G networks and AI, this scenario will provide a comprehensive solution for network infrastructure monitoring that can help to reduce costs, improve efficiency, and minimize the environmental impact of the network.

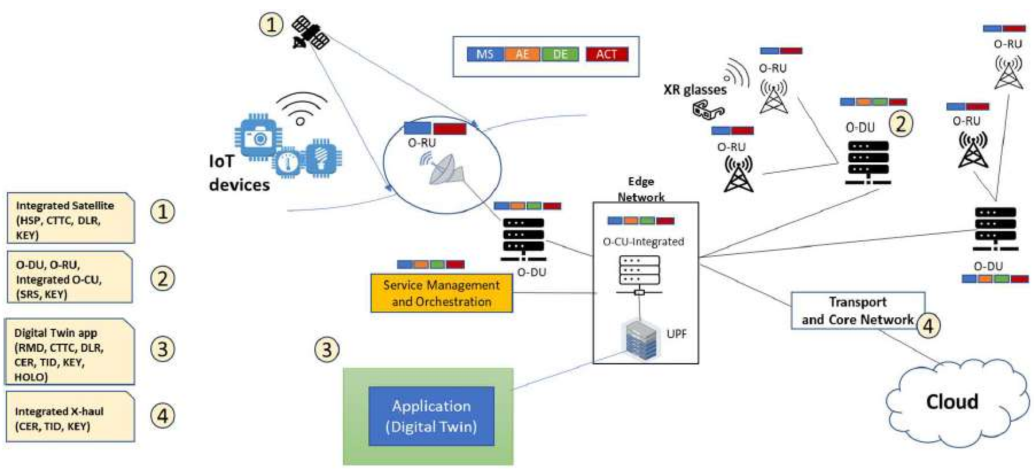

Figure 4-3 PoC#1-ES#3 Network Evaluator with GenAI data enhanced DT

PoC#1-ES#3 related objectives: Obj#1 and Obj#4

Relevant KPIs of PoC#1-ES#3:

- **KPI#26:** Increase the ratio of service management and LCM tasks resolved by local AE/DE components.
- **KPI#27**: Reduction of 80% of training/inference time of AI/DRL-based algorithms (relying on AI assisted data generation).
- **KPI#28:** An average accuracy of up to 90% in energy consumption and 80% in resource allocation compared to a testbed instance.
- **KPI#29:** Generate accurate and reusable GenAI enhanced data for DT.
- **KPI#6:** Decrease service creation and termination time.
- **KPI#31**: Reduce service recovery time below 180s.

4.4 POC#2-ES#1: ENABLING END-TO-END TIME SENSITIVE SERVICES OVER MULTI-RAT O-RAN-BASED UNITY-6G ARCHITECTURE

In this PoC #2, the UNITY-6G architecture adopts multi-RAT for supporting seamless end-to-end time sensitive application over 6G multi-Radio Access Technology (RAT) NPN deployments (Figure 4-4). To unify the RAN control and management on both technology segments (IEEE 802.11 and cellular 6G), an O-RAN enabled IEEE 802.11 AP will be designed and implemented. More specifically, the IEEE 802.11 AP will be advanced to terminate the O1 and E2 O-RAN interfaces in southern bound. This will enable the integration of the IEEE 802.11 network segment in the O-RAN control and management architecture, while the data plane from the IEEE 802.11 AP will be directly connected to the wired TSN switches in the back end bypassing the 6G core network. For this scenario, the multi-RAT NPN may be made accessible through a common network-exposure layer that provides APIs to query status information from O-RAN components, TSN-enabled IEEE 802.11 access points and the 5G/6G core.
The architecture for this ES is shown in Figure 4-4. On the left-hand side, the TS client (e.g. OPC UE client) is connected to a multi-RAT end device that supports time sensitive communication over wireless for both 6G cellular and IEEE 802.11. On the right-hand side, the TS server (e.g. OPC UE server) is connected to the multi-RAT RAN via the UNITY-6G core network and TSN wired network for the data plane. From the control and management point of view of the multi-RAT, two options will be explored. In the first option (option 1.1), both O-RAN enabled IEEE 802.11 AP as well as O-RAN enabled 6G base station will be controlled directly from a global RIC. In option 1.2, technology specific RICs will be introduced, that will be subordinated to a global RIC. Moreover, the data and control plane

inside the UNITY-6G core network will be enhanced with TSN switches to support time-sensitivity in the cellular core part as well (option 2.1).

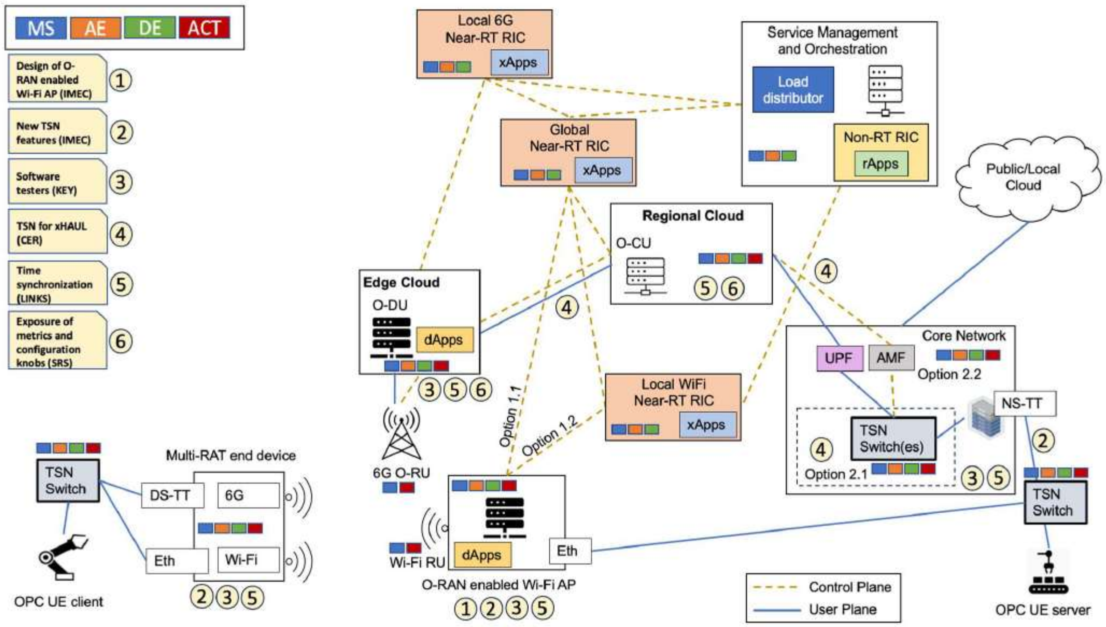

Figure 4-4 PoC#2-#1 Enabling end-to-end time sensitive services over multi-RAT O-RAN-based UNITY-6G architecture.

PoC#2-ES#1 related objectives: Obj#1, Obj#3 and Obj #5

Relevant KPIs of PoC#2-ES#1:

- **KPI#1:** Deliver four distributed management entities (namely MS, AE, DEs and ACT) deployable in each heterogeneous domain.
- **KPI#2:** Maintain end-to end latency (smaller than 20 ms) / reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context.
- **KPI#7:** Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms
- **KPI#11:** Cross-domain jitter of max of 2 milliseconds, with less than 10% of packets that missed the deadline.

An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution.

4.5 POC#2-ES#2: AI/ML-BASED MULTI-RAT RESOURCE OPTIMIZATION ON TOP OF THE TIME-SENSITIVE UNITY-6G ARCHITECTURE

In this PoC we will demonstrate the resource optimization of multi-RAT time sensitive NPN deployment utilizing AI/ML algorithms. We will demonstrate an ML pipeline for IEEE 802.11 and cellular 6G, including data collection, data processing, ML model training and inference, and ML output distribution. The dApps/rApps/xApps that will be developed in WP5 will be demonstrated in their ability to control and optimize the multi-RAT towards supporting the time sensitiveness of the traffic flows. A set of monitoring metrics and controllable features on both network segments will be exposed to be exploited by the different RIC APPs for radio resource management and network optimization. From the IEEE 802.11 network segment, among others, the following parameters will be exposed: Modulation and Coding Scheme (MCS) index selection, EDCA parameter selection, time-aware scheduling/shaping in the wireless link, transmit power updates, CCA threshold updates etc. From the 6G cellular network segment several monitoring and configurable parameters will be exposed such as signal-related metrics (e.g. Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ)), Channel Quality Indicator (CQI) measurements, MCS measurements/control, Radio Resource utilization parameters, time-aware scheduling/shaping in the wireless link, UE throughput related measurements (e.g. distribution of downlink/uplink UE throughput), and other. The system will be designed to optimize resource allocation across different domains (cellular and IEEE 802.11) to enable time-sensitive communication in end-to-end fashion. In addition, the ES will demonstrate the system's capability for dynamic AI-based routing across different domains. In Figure 4-5, we show the end-to-end multi-RAT network architecture and the distribution of MS, AE, DE, and ACT elements on each network node. Monitoring will be done on each network node and on per-traffic flow utilizing among others in-band network telemetry. Such monitoring parameters will be fed to the DEs located in local and/or global RIC, which in turn will employ actuators on each network node to configure certain parameters. Moreover, each node capable of performing monitoring should be capable of analysing data locally and inferring local knowledge. To this end, AI/ML models can be configured to consume input from standardized network-exposure APIs delivering time-aligned telemetry streams from the RAN, transport and TSN segments.

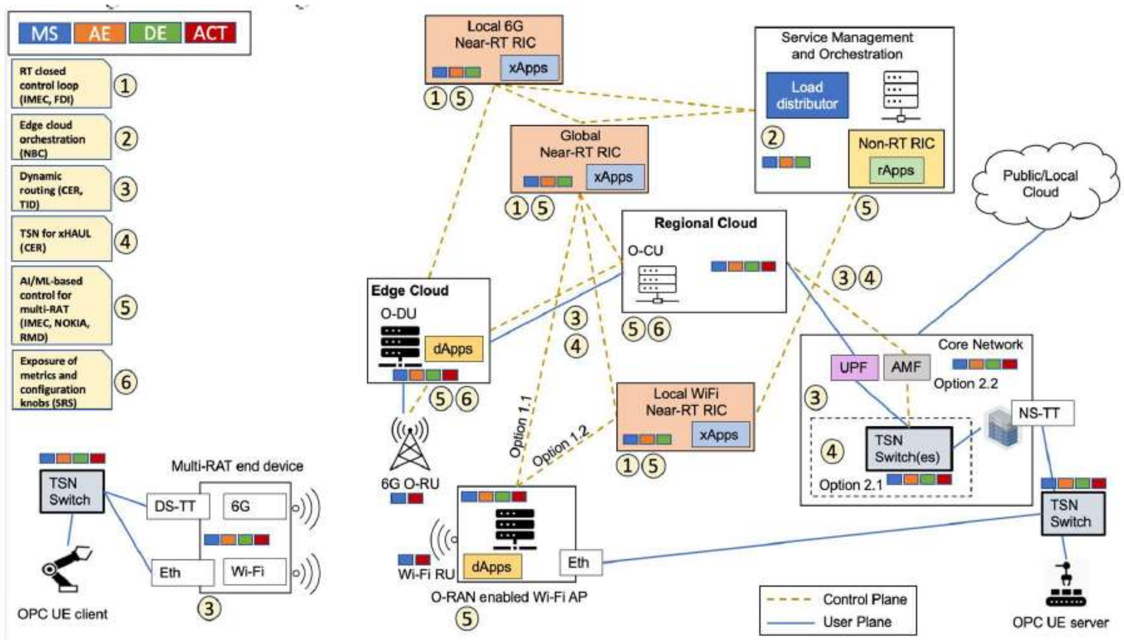

Figure 4-5 PoC#2 -ES#2 AI/ML-based multi-RAT resource optimization on top of the time-sensitive UNITY-6G architecture

PoC#2-ES#2 related objectives: Obj#1, Obj#2, Obj#3 and Obj#7

Relevant KPIs of PoC#2-ES#2:

- **KPI#4**: Real-time reconfiguration of IEEE 802.11 network domain in range smaller than 10 ms from taking the decision
- **KPI#5:** Real-time reconfiguration of cellular network domain in the range smaller than 10 ms from taking the decision
- **KPI#9:** Maintain end-to end latency (smaller than 20 ms)/reliability guarantees (99% of PDR) of time sensitive applications in a dynamic NPN context.
- **KPI#6:** Decrease service creation and termination time.
- **KPI#7:** Cross-domain (cellular – IEEE 802.11) end-to-end latency smaller than 20 ms.
- **KPI#18**: Cross-domain jitter of max of 2 ms with less than 10% of the packets missing deadline.
- **KPI#3**: An IEEE 802.11 traffic profile is expected to ensure below 10 ms latency (point to point, radio part) for the 99-th percentile of the delay distribution.

PoC#2-ES#3: DT service for management and load balancing of TS networks

In this PoC we will leverage the components developed and deployed in ES#1 and #2 to demonstrate the application of the DT technology for performance prediction and management operations in TS networks. This scenario will focus on building a DT model capable of faithfully reproducing the performance of the physical network counterpart in a TS scenario. To attain this goal, appropriate interfaces for data collection from the physical network will be defined, leveraging and integrating the interfaces defined in ES #1 and #2, to ensure that the DT can maintain calibration with respect to the time-evolution of the physical network, network load status, etc.

Similarly, calibration procedures for the DT will also be defined and demonstrated. Once the DT model has been developed and properly calibrated, its usefulness will be demonstrated in the implementation of the load balancing function in the TS network. The DT will be used to forecast the performance of different load-balancing configurations prior to their implementation in the physical network. The accuracy of the predictions from the DT will be assessed against the performance observed in the physical network. The goal is to leverage the DT to test network reconfigurations and load-balancing in the digital realm first, i.e. prior to incorporation into the physical network. If the DT predictions are sufficiently accurate, implemented changes in the physical network should imply no disruption in the network service, thus maintaining the tight latency service requirements of TSN. Still, application-level TSN DT can be driven by measurements made available through exposure APIs that report end-to-end latency, jitter and reliability per critical flow.

PoC#2-ES#3 related objectives: Obj #1and Obj#4

Relevant KPIs of PoC#2-ES#3:

- **KPI#9:** Guarantee end-to-end latency (smaller than 20 ms)/reliability guarantees (99% of PDR) of time sensitive applications after reconfiguration.
- **KPI#7:** Guarantee cross-domain (cellular-IEEE 802.11) end-to-end latency smaller than 20 ms after reconfiguration.
- **KPI#18:** Guarantee cross-domain jitter of max of 2 milliseconds, with less than 10% of packets that missed the deadline.
- **KPI#12:** Guarantee a prediction accuracy on end-to-end latency and jitter of 99.9%.
- **KPI#13**: Ensure a calibration delay smaller than one second (non-real-time applications).

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5 CONCLUSIONS

This deliverable has presented a comprehensive overview of the techno-economic landscape, and the strategic opportunities associated with the development of 6G networks within the UNITY-6G project. It has outlined the key stakeholders, market dynamics, and the critical requirements necessary for the successful deployment of future 6G architectures, emphasizing the importance of open, intelligent, and sustainable network solutions.

Additionally, the document has provided an in-depth description of the UNITY-6G project use cases detailing four primary use cases (sustainable disaster response networks, real-time XR/holographic communication, DT-based network evaluation, and multi-RAT O-RAN enabled NPNs for Industry 4.0), highlighting their technical requirements, KPIs, KVIs and potential business benefits. The work also outlined the evolving ecosystem of key stakeholders, including network operators, vendors, standardization bodies, and industry verticals, emphasizing the importance of open, flexible, and sustainable architectures.

Furthermore, the deliverable introduced the PoCs that will validate the integration of the UNITY-6G use cases in real-world scenarios, paving the way for scalable and resilient 6G deployments. The link between these use cases and the UNITY-6G architecture will be explained in the next deliverable D2.3, which will present the first release of the UNITY-6G architecture.

Moving forward, the focus will be on executing the planned PoCs and use cases, refining the DT models, and further developing AI-driven automation and resource management strategies. These efforts will support the realization of a sustainable, high-performance, and flexible 6G ecosystem.

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